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A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Life Member shall be a member whose service to the Association entitles him to special recognition by the Association.

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An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

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This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

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SOIL CORROSION AND ITS EFFECT UPON PIPING AS SHOWN BY THE TESTS OF THE UNITED STATES BUREAU OF STANDARDS.

BY JOHN D. CAPRON.*

[*Read March 8, 1927.*]

In recent years there has been a marked increase in interest in the problems of corrosion. This is indicated by the fact that studies of this subject have been undertaken by a number of organizations, including several large public utility corporations, the manufacturers of pipe, and several of the more important national societies, such as, the American Water Works Association, American Gas Association and the American Foundrymen's Association.

One of the most extensive of these corrosion studies is being conducted by the United States Bureau of Standards in coöperation with a number of pipe manufacturers and public service companies. This is in every sense of the word a joint investigation and each of the organizations coöperating has contributed in some way to the work. There are now approximately 90 individuals or companies furnishing material, labor or technical advice and direction.

The information that is secured in this investigation is made availab le to the public as fast as circumstances permit, and it is possible, therefore, for all those who are interested in the work to keep informed as to its progress.

As a representative of one of the pipe manufacturing companies furnishing material for these tests, the writer has kept in close touch with the investigation since its inception and has personally inspected many of the test stations, assisted in removing the specimens, examined them before and after they had been cleaned, and participated in the preparation of the reports on their condition. As the results of the tests are available to anyone who desires them, the writer feels at liberty to comment freely upon the findings of the investigation.

As is well known, the Bureau of Standards, organized originally for maintaining the primary standards of weights and measures, has in recent years broadened the scope of its activities and is now conducting many

*Research Engineer, U. S. Cast Iron Pipe & Foundry Co., Burlington, N. J.

investigations bearing on the standardization of manufacturing methods, processes and materials. Most of these undertakings are actively assisted by the coöperation of those branches of industry directly concerned.

The purpose of "The Bureau of Standards' Soil Corrosion Investigation" was primarily to determine under what circumstances soils were responsible for the deterioration of underground pipe systems. To accomplish this it seemed necessary to study many soils, and, as the Bureau of Soils of the Department of Agriculture had already undertaken to classify soils, this bureau was asked to indicate the location of characteristic

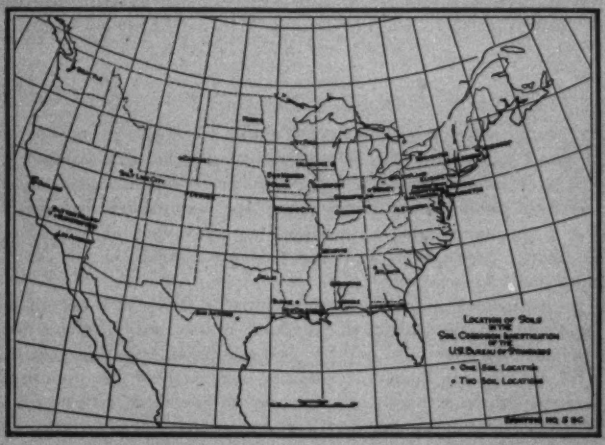
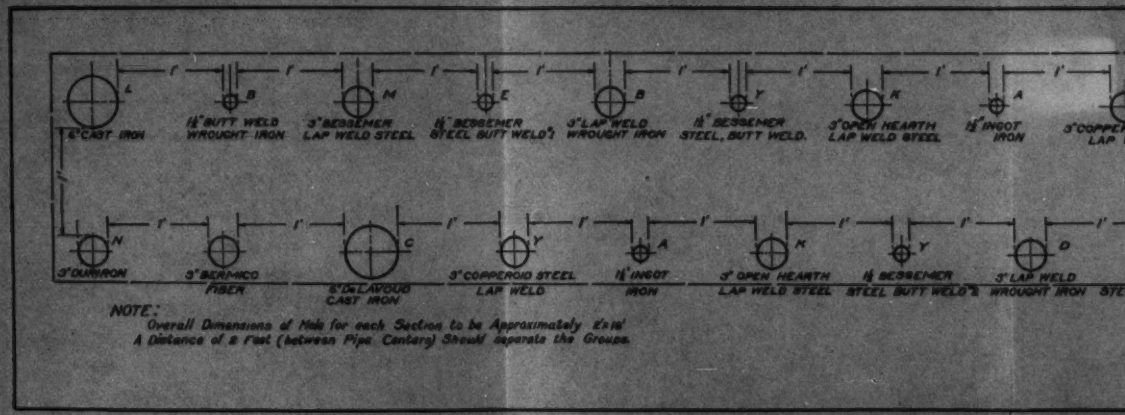


FIG. 1. — MAP SHOWING LOCATION OF SOILS USED IN TEST.

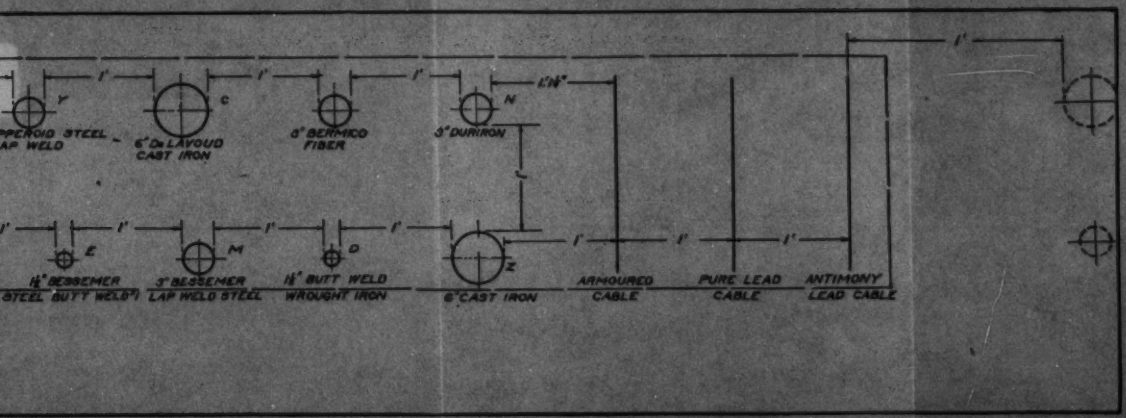
soils that would establish the greatest variety of test conditions. Forty-six soils located in 32 widely-separated localities were selected. In order that the data might be applicable to most working conditions the common commercial pipe materials were chosen for test. After the work was started additional materials consisting of pipe fittings, galvanized sheets and protective coatings were added. In 1926, other materials were added in a few locations.

The pipe specimens were placed on end and filled with earth in order to expose a maximum amount of surface to the soil. Six groups of specimens were originally buried at each location so that one group could be removed from time to time without disturbing the others. The additional materials were similarly buried in groups.

Up to date, approximately 14 000 specimens have been buried and some 2 000 specimens have been removed for examination. The materials under test include 20 varieties of bare iron and steel pipe materials; 24


6" CAST IRON
1½" BUTT WELD WROUGHT IRON
3" BESSEMER LAP WELD STEEL
1½" BESSEMER STEEL BUTT WELD
3" LAP WELD WROUGHT IRON
1½" BESSEMER STEEL, BUTT WELD.
3" OPEN HEARTH LAP WELD STEEL
1½" INGOT IRON
3" OURAIRON
3" BERMICO FIBER
6" DELAVOUD CAST IRON
3" COPPEROID STEEL LAP WELD
1½" INGOT IRON
3" OPEN HEARTH LAP WELD STEEL
1½ BESSEMER STEEL BUTT WELD
3" LAP WELD WROUGHT IRON
NOTE:
Overall Dimensions of Hole for each Section to be Approximately 6'x6'
A Distance of 2 Feet (between Pipe Centers) Should separate the Groups.

SHOWING ARRANGEMENT OF UN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varieties of non-ferrous metals; 17 kinds of bituminous coatings, galvanized pipes and sheets with six weights of coating, as well as two specimens each of lead and aluminum coatings.

As will be shown by the results of the investigation, the nature of the soil is as important as the nature of the material, and one following the

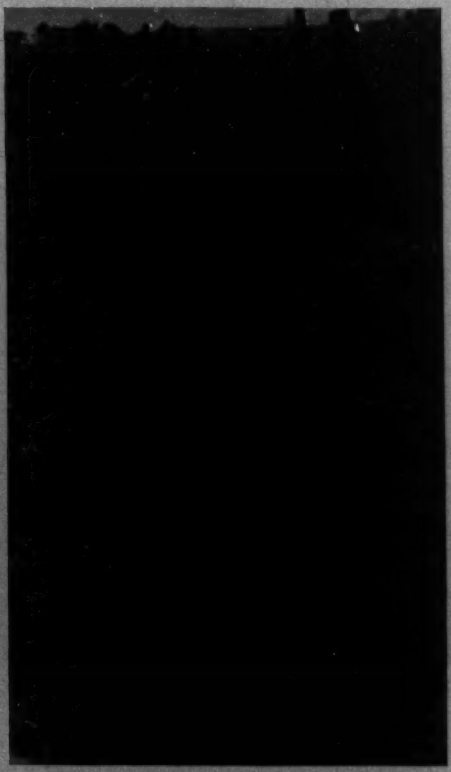

FIG. 2. — ORIGINAL SPECIMENS IN TRENCH AT ALEXANDRIA, LA.

investigation must study soils as well as metals. The variation of soils is, however, less well understood and harder to demonstrate. Figs. 2 and 3 were taken in the course of a trip for burial and removal of specimens. They show some of the specimens about to be buried and give a rough idea of some of the physical characteristics of the soils.

The placing and removal of specimens is not an easy task. One set of specimens, for example, is buried in a Louisiana swamp near an oil line that lasts about six years. Here the soil is very wet. Another set lies in the muck of a southern city not far from a water line that has been subject to severe corrosion.

After specimens are removed they are sent to the Bureau of Standards to be cleaned, weighed and measured for pits. They are then placed on

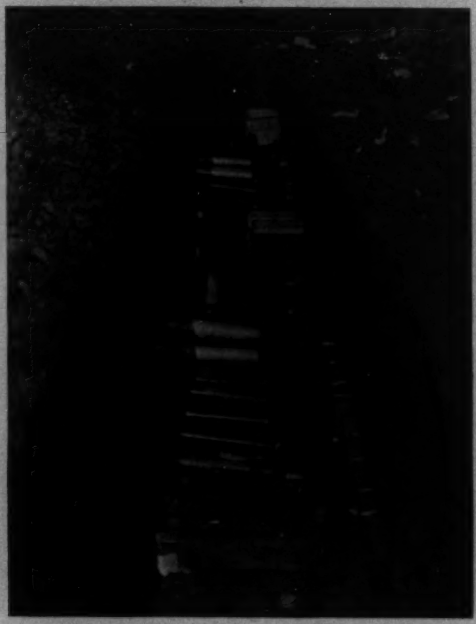

FIG. 3. — LARGE GROUP OF SPECIMENS IN TRENCH AT MERIDIAN, MISS.

exhibition, and all interested persons are invited to examine them. The magnitude of the undertaking is obvious when we consider that approximately 1 000 specimens of bare pipe were removed in 1926 and, at the same time, almost as large a number of coated sheets and pipes were on display. Several hundred additional miscellaneous specimens were also removed in 1926.

A study of these specimens shows several things of interest. In any one soil the type of corrosion is similar in all the rolled materials. In Fig. 4, are shown specimens of open-hearth iron (*a*); copper-bearing steel (*c*);

wrought iron (*d* and *e*); open-hearth steel (*k*); and Bessemer steel (*y*). Plainly the type of corrosion here is controlled by the soil rather than by the pipe material.

In different soils the nature of corrosion often differs materially. Fig. 5 shows the following specimens of Bessemer steel: Specimen No. 1 from a well-drained gravelly soil shows almost no corrosion; the second specimen (No. 2) had been buried in a wet silt loam — it has lost the oxide coating,

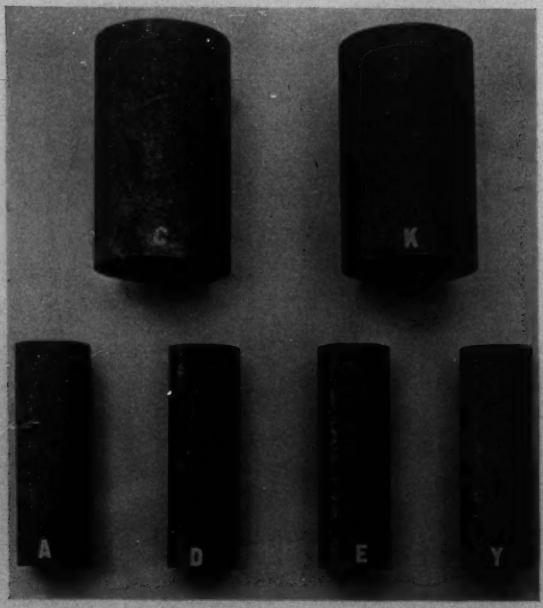

FIG. 4. — SPECIMENS OF ROLLED MATERIAL FROM THE SAME SOIL SHOWING SIMILARITY OF CORROSION.

but shows a smooth surface with no pits; the third specimen (No. 3) had been buried in a loam usually moist and has a roughened surface; specimen No. 4 had been in a silt loam, moist at times and dry at others — it shows patches of light corrosion with areas of the original surface; No. 5 from a sandy loam shows a few pits; while No. 6 from a silt loam shows numerous deep pits; No. 7, which has a worm-eaten appearance, is from a sandy loam; No. 8 had been buried in a soil containing white alkali — it is badly corroded over most of its surface, has a hole through the wall and shows serious corrosion where it was welded. Different soils affected the cast-iron speci-

mens differently and produced variations in corrosion similar to those of the steel specimens.

All of the specimens referred to had been buried approximately four years. They show that the character of the soil plays a large part in determining the extent and character of the earlier stages of corrosion of buried pipe. Whether later specimens will show the same tendencies and whether, after a longer period of burial, some one material will prove markedly superior cannot yet be stated.

FIG. 5. — VARIATION OF CORROSION OF STEEL SPECIMENS.

That the soil rather than the type of material is the determining factor in soil corrosion is indicated by plotting the rate of pitting against the hydrogen ion concentration of the soils under investigation. This has been done in Fig. 6. Data on the rates of corrosion of six classes of material in 49 soils are used. The materials considered are wrought iron, pure open-hearth iron, Bessemer steel, open-hearth steel, copper-bearing steel, and ordinary cast iron. It will be seen that the curves for the rolled material follow each other rather closely and that the cast materials show similar tendencies although they deviate more from the average. The curves also show the wide variations in rates of corrosion in different kinds of soil.

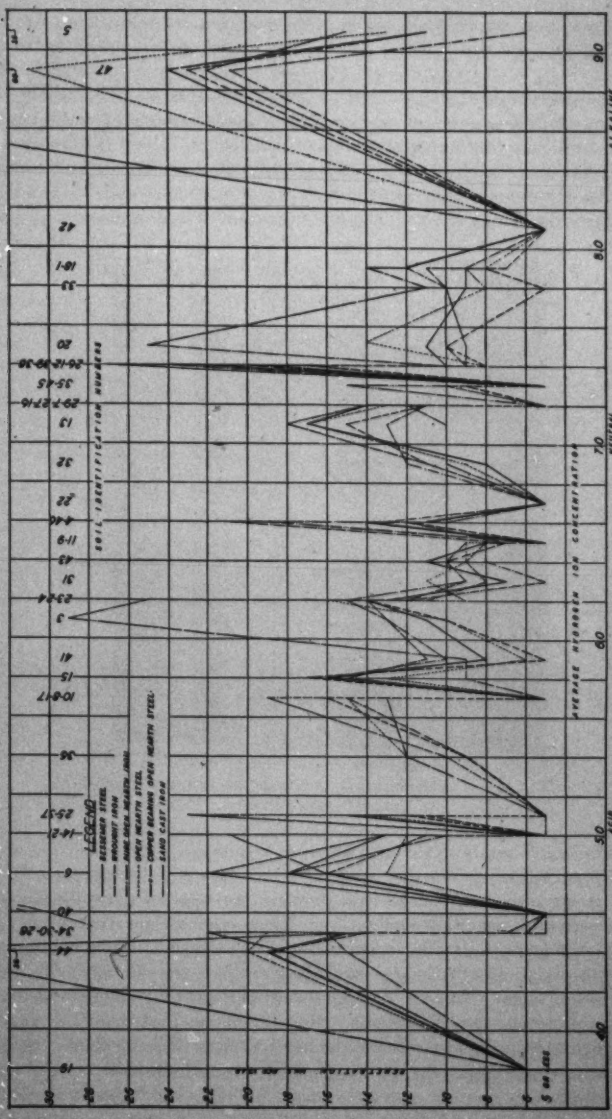

FIG. 6. — RELATION OF pH VALUE TO DEPTH OF PITTING.

It follows, that the soils should be studied so that we may determine, if possible, why they are corrosive and what can be done to mitigate their action.

It is the writer's belief that the depth of pitting is of far more importance in determining the life of pipe than is the loss in weight and for this reason only curves showing the rates of penetration of pits in the several kinds of ferrous materials under test are here presented.

The curves show that while in highly acid or alkaline soils the rates of corrosion and pitting are high the determination of hydrogen ion values is

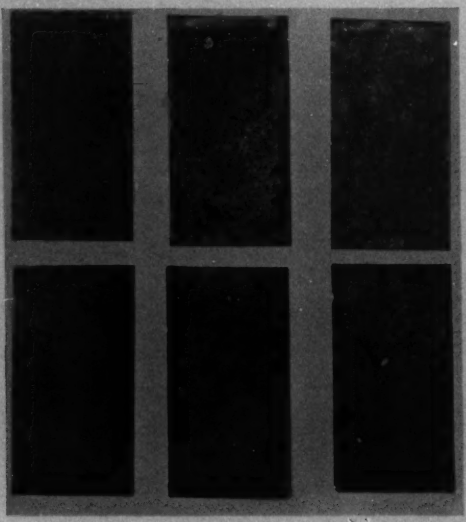

FIG. 7. — CORROSION OF GALVANIZED AND BLACK SHEETS IN THREE DIFFERENT SOILS.

not sufficient to establish the corrosiveness of many kinds of soils. To find out whether the amounts of soluble salts in the soil determine its corrosiveness, curves may be plotted showing the relation of water-soluble salts to rates of corrosion and pitting. Such curves show that while, in general, the corrosion tends to increase with the amount of salts in the soil water, the relation between the two is not fixed. The electrolytic theory of corrosion might induce us to think that soil resistivity offers a key to the interpretation of soil corrosion. Plotting one against the other shows that one may expect more corrosion in highly conducting soils than in those of high resistivity but as in the case of pH and salt content the rule has many exceptions.

Part of the apparent lack of relation between soil characteristics and corrosion may be accounted for by the fact that the soil data were taken only at times when specimens were being buried or removed, and that soil conditions may vary materially in the intervening period. The test data may not represent the soil conditions during the periods in which corrosion was occurring.

Another explanation of the apparent lack of relation is that there may be several factors that influence the rate of corrosion. One of these may predominate in one soil while in other soils another factor may be the determining one. That some soils are corrosive seems to be fairly well established. "The Bureau of Standards' Test of Coatings" throws a little

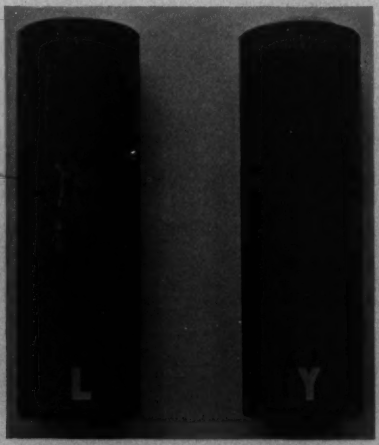

FIG. 8. — CORROSION OF UNPROTECTED AND LEAD-COATED PIPE IN A SALT MARSH.

light on how corrosion may be mitigated but it is far from complete and must be supplemented before the problem can be considered solved.

It has been shown that the ferrous metals behave more or less similarly. The action of the soil on other metals is also severe in some localities but, fortunately, in a number of cases the same soil is not equally destructive to all metals. Thus it was found that in Marshall Silt Loam lead corrodes much more severely than galvanized iron while in Summit Silt Loam the reverse is true.

Fig. 7 shows the corrosion of galvanized and black steel sheet in three soils: in the first, Susquehanna Clay, the black steel has pitted through while the galvanized sheet still retains much of the coating; in the second, a muck, the black steel was in a better condition, but the galvanizing had

almost completely disappeared; in the third, a salt marsh, both the black and galvanized sheet are better than in the muck.

One might expect that any protective coating would add at least a little to the life of a pipe. Unfortunately, this is not always true. In Fig. 8 are shown a lead coated (L) and an uncoated Bessemer steel (Y) specimen taken from a salt marsh. The coated specimen has been punctured while the uncoated specimen is still in fair condition. As sheet lead in this soil did not corrode badly, it is thought that the failure of the coated specimen was due to pinholes in the coating.

In several locations a similar action occurred on specimens of pipe

FIG. 9. — CORROSION OF UNPROTECTED SPECIMENS AND SPECIMENS PROTECTED WITH UNSATISFACTORY COAL TAR.

coated with a coal tar which flowed, leaving parts of the pipe exposed as is shown in Fig. 9. These specimens (No. 1 coated and No. 2 uncoated) had been buried in an alkali soil for approximately four years. Several other locations gave similar results as is shown by specimens No. 3 (coated) and No. 4 (uncoated) from the salt marsh previously mentioned. Four kinds of bare iron and steel are shown from each location.

To add to the difficulties of coördinating the results of these investigations we have only to look at the specimens of brazed joints shown in Fig. 10. These specimens were buried two years in muck (pipe), Susquehanna Clay (No. 1) and Ruston Fine Sandy Loam (No. 2). When the metals are clean there is a difference in potential of from 0.1 to 0.2 volt between the bronze of the weld and the cast iron. According to the electrolytic theory of corrosion this should cause rapid corrosion of the cast iron which is anodic to the bronze. Examination of the specimens will show that there is little,

if any, more corrosion adjacent to the weld than elsewhere on the iron and the little which may be next to the weld might be attributed to the action of the welding flux.

Fortunately, the work which we have been discussing will continue for six years. During this time there will be opportunity to study the data further and to make other experiments. Progress has already been made and it can reasonably be expected that, if full use is made of the opportunities

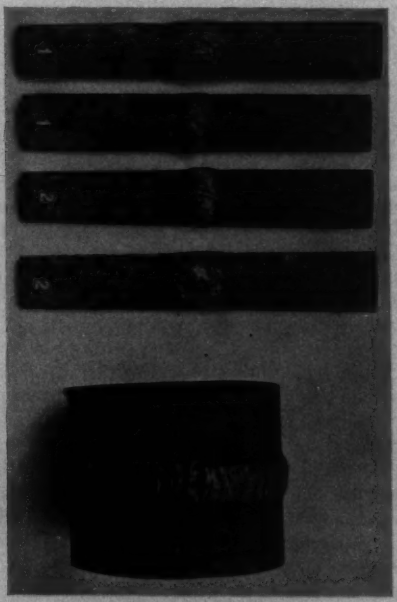

FIG. 10. — CORROSION OF BRONZE-WELDED JOINTS ON CAST IRON.

that the investigation offers, much valuable information will be added to our store of knowledge of soil corrosion.

Those of us who have followed this investigation carefully are fully convinced that the information derived therefrom will be of great value to all users of underground pipe lines. Certainly to be able to forecast the life of a pipe line in a particular soil and to provide for its protection, if necessary, will be helpful. The problem of soil corrosion in New England is not very serious. On the other hand, difficulties with tuberculation are here of importance. In this connection it is to be hoped that any information that will throw light on the causes and prevention of soil corrosion will be of assistance in solving the equally difficult problem of tuberculation.

Discussion.

Robert Spurr Weston.* Mr. President, I am very much interested in this paper, and I have been asking myself — as Mr. Capron has been going through these data and showing us all these slides where comparisons have been made between rate of corrosion and character of soil, character of soil waters, and character and amount of resistance of soil — whether or not some attention has been paid to the porosity of the soil. It has always been an idea of mine — a conception of mine, not an idea of my own, of course — that the corrosion of pipe is more or less a function of the rapidity with which the corroding solution comes in contact with any particular point of the metal. There must be, it seems to me, a difference between the rate of corrosion when a fine grained soil is packed close to a pipe, and when a coarse grained soil of the same chemical character is in contact with the pipe.

John D. Capron. That is a very important subject. The only reason why I did not touch on it in the paper is that the data available are as yet insufficient. The Government in these tests is making an effort to study the porosity of the soil in the field; also there are being run at Washington some very elaborated studies on the size of grain of sand and the corrosion which results from pipe in contact with sand of these various grains containing a corrosive solution. It is hoped, before long, to have something definite to report on this subject. In the case of the specimen showing the worm-eaten action which has brought up this discussion, I believe the final decision has been that it is slippage in the soil that allows the corrosive solution to get to the point of maximum corrosion more rapidly than to any other point of the pipe.

Edward B. Story.† We should be just a trifle cautious in using the data available at this time from the soil corrosion test for comparing the relative corrosion resistance of the various metals. The duration of the test to date is about four years and in some instances the samples have been buried even a shorter time.

As Mr. Capron has said in his paper, experience with corrosion in general would seem to indicate that the initial rate at which ferrous metals are corroded is practically the same whether the metal be cast iron, steel, pure iron, or wrought iron. Furthermore, as the time of exposure is increased, there seems to be a decrease in this initial rate. This does not necessarily mean that the decrease in rate will be the same for all the materials. Such retardation of corrosion rate is undoubtedly due to a number of causes, an important one being the formation of protective surfaces or films.

Such protective surfaces can result from the corroding medium or by the character of the rust formed or by combination of the two. The character of the material is also a very important factor in this connection, thus cast iron soon after solution of metal has started tends thereby to have

*Consulting Engineer, Boston, Mass.
†Of the A. M. Byers Company.

deposited on its surface a film or layer of graphite carbon. This graphitic layer can cause a marked decrease in corrosion rate. It is this feature that is largely responsible for the durability of cast iron in certain services. In this respect it is interesting to reflect that from a strict interpretation of the electrolytic theory, cast iron should show very little corrosion resistance.

Wrought iron is somewhat in this class. The fine even dispersion of silicate slag acts similarly to graphite of cast iron to produce a protective layer or film.

Another instance where a marked reduction in initial corrosion rate is similarly effected is in connection with copper-bearing ferrous materials subjected to atmospheric corrosion. Such copper-bearing materials form very hard dense rust, almost vitreous in character, which causes a very considerable decrease in corrosion rate.

I have carefully examined each of the thousand or more samples which have been unearthed during this past two-year period. Broadly speaking, there seems to be no outstanding difference between the various materials; but, to draw conclusions, based upon the results at this time, might be wholly erroneous or at least misleading as may be shown by future data on these tests, when the various factors such as film protection-effects will have had ample opportunity to fully function.

While one might, at this time, speculate as to the outcome, it would seem prudent to allow the test to run its contemplated period before real definite conclusions be drawn.

EFFECT OF CEMENT-LINED PIPES UPON THE QUALITY OF THE WATER SUPPLIED.

BY BURTON G. PHILBRICK.*

[*Read March 8, 1927.*]

Last summer while studying the operations of a bottling plant in Quincy, a careful supervision of the water supply was maintained as a matter of routine. In such a plant a water of high sanitary quality is necessary and the presence of sediment or suspended matter is especially undesirable. Since the water in use was taken from the city service which is supplied from the Metropolitan system, no difficulties were expected, nor were they encountered in the first part of the summer.

About the middle of August it was noted that whenever a sample of water was collected from a small soapstone storage box, a gray greasy scum appeared on the surface of the sample in the neck of the bottle. This condition was at first laid to the feed pipes or the tank itself. Measures were therefore taken to clean the pipes with hot soda solution and to scrub down the interior walls of the soapstone box. These measures failed to lessen the trouble.

Examination of the scum itself was difficult to make, as it was easily broken up by the jarring that it received while being brought to the laboratory. Centrifuging and examination of the sediment seemed to show a few micro-organisms and white sandlike particles.

One puzzling but interesting fact was that the material which collected on the surface of the water in the sample bottle was not present throughout the body of the water in the storage tank but only on the surface. Any ordinary foreign material such as molds or diatoms would be fairly evenly distributed and any grit or sand would be expected to collect at the bottom rather than surface of the water.

With the idea of locating the original source of the scum, the tanks, pipes, and filters, were eliminated one by one and finally the same scum was detected in the water as drawn directly from the service tap itself. It was found that when the tap water was allowed to run directly into a clean earthen jar, an oily or greasy scum was noticeable on the surface of the water as one looked down onto the dark sides of the jar.

Since it was evident that the origin of the trouble was outside the plant, information was sought regarding an unusual supply which might be in use, or any other unusual condition which might offer an explanation. At first nothing could be discovered out of the ordinary regarding the supply or distributing system. On further inquiry, however, it was learned that new pipes were being laid. On inquiring of Mr. Sherman, of Metcalf

*Of Skinner, Sherman & Hazelton, Inc., Chemists and Engineers, Boston, Mass.

and Eddy, under whose direction the work was being done, if there were any unusual conditions, it was learned that the new pipes were cement-lined.

A comparison of the date of the first use of the cement-lined pipes and the date of the appearance of the scum showed a close coincidence. This made it seem very probable that the scum was due to the action of the water on the cement lining and brought quickly to the mind the similarity in appearance between the scum on the Quincy water and that familiar scum found on the water pans in which cement briquettes are aged before breaking for test. This similarity was confirmed by microscopical examination of both in which the characteristic crystals of calcium carbonate were easily identified. These crystals form at the surface and float there gathering to themselves such dust as may fall from the air, forming a scum which has a dirty gray greasy appearance. The fact that the scum was mainly calcium carbonate also explained a circumstance which had already been noted, which was that it seemed to be absent after carbonation of the water. This was due to the change of the carbonate to the more readily soluble bicarbonate by the excess of carbon dioxide gas.

Since the use of cement-lined pipes is by no means new and since their use is steadily increasing as a defence against corrosion losses, it was thought that there might be some interesting data in engineering and water-works literature. A fairly careful search has failed however to bring to light any direct reference to the effect of the cement lining upon the water supplied through them except in one case. This writer briefly states that there is no appreciable effect and from the sparsity of references we may conclude that either he is correct in the majority of cases, or that the effect has not been noticed because the conditions of the pipe itself rather than the water has been the chief object of the observation.

Personal conversation with several water laboratory men and engineers has revealed that this formation of scum is not uncommon. It has been frequently noted in Rhode Island where the farmers have sunk cement pipes in their wells and on noticing the dirty surface scum have appealed for advice or information to the state laboratory. Mr. Weston, of the Massachusetts State Department of Health, has also given figures obtained from analyses of a Taunton service tap water. This water comes through 475 ft. of cement-lined main which forms a sort of dead end. The analyses show an increase in hardness from 10 p.p.m. to 80 p.p.m. due to flowing through the cement-lined main. This is of course an exaggerated effect but shows clearly the effect of a cement lining. It should be stated here that so far as can be determined, the Quincy water cleared up by October and no more scum is noticeable.

It is certain that cement-lined pipes will be used more extensively in the future. With this in mind and realizing the necessity for an absolutely clear water in certain industries and the increasingly critical attitude of the individual consumer, I believe that more cases such as noted will come to light.

Discussion.

George A. King.* The speaker referred to Taunton and the result of the examination of water from one of the new mains we put in last year. This was decidedly a dead end. It is only a temporary dead end, but there is quite a body of water there, and no good opportunity to blow it off. We had a complaint from a party living near the dead end, Mr. Weston sent down, and we got a sample which on examination showed the increase in hardness referred to by the previous speaker. Mr. Weston suggested that we take another sample from some other place where there was a much longer pipe supplying the water, and there we found no increase in the hardness. Taunton has used cement-lined services for nearly 50 years, and we never have had any trouble from them. A great many other cities in Massachusetts have also used such services, and so far as I can find from inquiries, there is no trouble from the use of cement-lined pipe. Some 21 years ago the State Board of Health undertook the examination of a great many of the services of the different cities and towns of the state, and from such of the data as I could obtain there is in most of the samples no increase or but little increase in the hardness of the water. In a few cases there was an increase, but not a material one.

In Plymouth they have cement-lined mains and lead services, and in this examination by the Board of Health there was very little increase in hardness found in water taken from the taps. Milton, Mass., Concord, N. H., and Hartford, Conn., have all used them.

Patrick Gear.† This is going to be a serious problem if we are using cement-lined pipe and it is going to be injurious to the health; we should stop it. There are many members of the Association using cement-lined pipe; I am one of them. Is it a fact that water passing through a cement-lined pipe is more injurious to the health than water that goes through a cast-iron pipe having a couple of inches of dirt on the bottom of it; or is it a fact that cement-lined pipe is so clean that the sediment that would stay in the cast-iron pipe would move along in the cement-lined pipe and go into the bath tub? If the statement ever gets into the papers that cement-lined pipe is going to be injurious to the health, and the women get hold of it, we will have a job on our hands to take the pipe all out.

Mr. President, of course it did not strike me as quickly as it did Mr. Saville that we should have a committee to investigate this question, but I think it a wise move to have one.

In 1911 or 1912 the owner of one of the large apartment buildings in Holyoke complained of the hot water being dirty. The superintendent at that time told me to go and see about it. I went to see it and found a tank that contained about one thousand gallons of hot water. There was a large space around the tank that was connected with the sewer. On letting the water out it was found to be alive with insects. I told the owner that it was the tank that caused the trouble. "What are you talking

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†Superintendent, Water Works, Holyoke, Mass.

about — what do you know about it?" asked the owner. I answered "All right, I have a report here on just this matter. Do you want to read it?" He said "No." The city of Springfield had the same trouble about 1910 and they engaged Hazen & Whipple to investigate. They took different sections of Springfield — new and old apartment buildings with various makes of tanks — and found that the trouble was in the tanks of the later apartments. The manufacturers of these tanks called a meeting in Springfield and hired a distinguished attorney to fight the case, but he advised against such action and suggested changing their type of tank.

Now if we have a report from a committee with men that I know will be put on it, we will have a report that will set us right, and we can show it to those fellows that complain about dirty water. I hope it will tell if it is right or wrong to be using cement-lined pipe, and if it is injurious to the health of men, women and babies.

FRANK A. MARSTON.* Mr. President, having had a personal interest in the work which was done last year at Quincy for the reinforcement of the distribution system, I was much interested in the difficulty experienced by Mr. Philbrick with water at the bottling plant. This is the only case of its kind that has come to my attention. My residence is located near the line of 20-in. cement-lined pipe which was installed last year, but I have observed no such conditions as those described by Mr. Philbrick.

The cement-lined pipes have now been in use for six months or more without any complaints regarding quality of water that might be attributed in any way to the cement lining.

ROGER W. ESTY.† I think the citizens of our town would feel alarmed if a cement-lined pipe was not used.

Our system was started in 1876 and the old-type sheet-iron cement-lined pipe was used. In 1910 we started relaying the system with just a plain cast-iron pipe.

There has always been considerable talk of trying to obtain a cement-lined cast-iron pipe. This last year we laid five miles of cement-lined cast-iron pipe, from 4 in. to 20 in., of which our main trunk line, three miles long, was laid with a 20 in. This passes my residence on the way to the center of the town. We have not had any complaints whatsoever, to date, from anybody along the main line, or from the side streets that this line is supplying.

The only trouble we have had this year or at any other time, even with a service pipe, has been for about ten days on a dead-end line.

Now this last year it is true that on a 6-in. line, half a mile long, the customers did complain about this scummy substance forming on pans or in the sink where water was standing, but after blowing the main off numerous times we have not heard of any complaints since; and as to service pipes we have had complaints from those of 100 to 150 ft. long, but by constant flushing for 10 to 20 days the trouble gradually rights itself.

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†Superintendent, Danvers Water Board, Danvers, Mass.

I do not feel that anybody should feel so alarmed about cement-lined pipe.

CHARLES W. SHERMAN.* I feel responsible for getting this paper before this Association, and I believe I did a pretty good thing. Mr. Philbrick discovered, in the very early days of the use of cement pipe in Quincy, some trouble which he could not locate at first, and which seems to have been related to the use of cement pipe. That same trouble, or a similar trouble, may occur to any one of us who is using cement pipe; and it seemed to me it was of great importance for this Association to get the earliest possible information of this kind, and to know what has happened in other cases, and as far as possible know the explanation for it, and what to say if trouble does come. I think the paper has been of very real help to us in getting that information and in learning what might happen. The fact that tastes have been noticed in long service lines and in dead-end cement-lined mains is another indication that cement-lined pipes are not wholly free from the trouble that we occasionally associate with tar-lined pipes.

I believe it will be wise for the Association to proceed with the appointment of a committee, as suggested by Mr. Saville, to follow out the matter as far as it is practical at this time. I do not believe that we are going to find more than a very few cases of anything more than increased hardness, but there is this one case where at least a scum has been noticed, and there may be others if we look into it; and the more we know about it, the better situation we are going to be in to meet any complaints that may come up, and the more justification are we going to have for the use of cement-lined pipes, which I believe in most heartily.

GEORGE A. KING. Mr. Esty brought out a point that leads to a personal matter which I would like to mention. Yesterday at my house there was a complaint from the laundry of a scum on the water. Now, my service pipe had been in more than 20 years. I am all of half a mile from the nearest cement-lined main, and there is no probability of the water coming through that main to my house; yet we have the very scum that has been mentioned. This was not apparent the following week.

DAVID A. HEFFERNAN.† I have had about 37 years experience in Milton and we have had some cement-lined pipe which has seen that number of years service. In all that time we have never had a complaint about the taste of cement in the water.

We have had complaints of poor pressure in lead supplies. Following the first complaint we forced a wad of tissue paper through the pipe having first disconnected it at the corporation. I was astounded at the quantity of slimy substance which came through.

Last year we laid cement-lined pipe in sizes from 6-in. to 16-in. and have received no complaints as yet. My experience with cement-lined service pipe makes me feel that we will be eminently satisfied with a similar lining in the main pipes.

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†Superintendent, Milton Water-Works, Milton, Mass.

PUBLIC WATER SUPPLIES OF MAINE.*

BY ELMER W. CAMPBELL.†

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Abbott, E. A. Water Company.

Supplies 44 families in the town of Mexico. Installed in 1901. Obtains water from three springs. The springs are walled up to make small reservoirs with a total capacity of 50 000 gal. The water flows to the customers by gravity. About three-fourths of a mile of mains. Color 5. Hardness 44. Chlorides 7. Quality of water excellent.

Arcadia Aqueduct Company.

This is a small spring water supply furnishing water to a portion of the village of Castine. Constructed in 1898. Water is pumped by windmill to a storage and distributing reservoir of 12 000 gal. capacity. About one mile of mains. Color 6. Hardness 29. Chlorides 8. Quality of water excellent.

Alfred Water Company.

The town of Alfred, population 738, is supplied with water from a small lake about a mile from the village. Constructed in 1912. The water is pumped by electric power to a standpipe, capacity 278 000 gal. Three and one-half miles of mains. Color 14. Hardness 18. Chlorides 4. Sanitary quality of water excellent.

Allen, Mrs. M. A.

Columbia Falls, a village of 658 persons, is supplied from a spring. The system, installed in 1911, consists of a storage reservoir of 70 000 gal. and about one-half of a mile of mains. Water flows by gravity. Color 7. Hardness 44. Chlorides 6. Sanitary quality excellent.

Andover Water Company.

Organized in 1909. Supplies the village of Andover by means of a gravity system obtaining water from a mountain brook that flows through wild timber lands. About two and one-half miles of mains, delivering water to about 700 people. Color 17. Hardness 21. Chlorides 4. Quality of water excellent.

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*Editor's Note. This paper is the third in a series presenting statistical information on the Public Water Supplies of the New England States. For Massachusetts Water Supplies see Vol. 38, 1924, pp. 144–197. For Rhode Island Water Supplies see Vol. 40, 1926, pp. 117–127.

†Director, Division of Sanitary Engineering, Maine State Department of Health.

Anson Water District.

Supplies the village of North Anson in the town of Anson. Total population 2 563. The water is supplied by gravity from the Madison Water District. Twenty miles of mains. Constructed in 1916. Color 17. Hardness 20. Chlorides 4. Quality of water excellent.

Auburn Water District.

Water for the Auburn Water District is pumped by electric power from Lake Auburn to two reservoirs, capacity 7 250 000 gal. A population of 16 985 is supplied. The system was installed in 1871. There are now 59.19 miles of mains. Chlorinator installed November, 1923. Color 6. Hardness 25. Chlorides 4. Quality of water, excellent.

Augusta Water District.

The Augusta Water District, with a total population of about 15 000, consists of the village of Manchester, the National Soldiers' Home, a portion of East Winthrop and the city of Augusta. The original system, installed in 1886, took water from the Kennebec River. The source was changed in 1906 to Carleton Pond about eight miles from the city. Water at times of high lake level flows by gravity to a storage and distributing reservoir, 5 000 000 gal. capacity. Electric booster pumps are provided. A standpipe, capacity 350 000 gal., is located at the National Soldiers' Home. Chlorinator installed November, 1923. Fifty-four miles of mains. Color 17. Hardness 30. Chlorides 4. Quality of water excellent.

Bangor Water Department.

Total population supplied 26 978. The water works was constructed in 1875, taking water from the Penobscot River. Under the present laws no state or municipal authorities have sanitary control of the river, which receives sewage from towns located along its banks. Water power is used for pumping, but a reserve power of steam is maintained. A standpipe, capacity 1 750 000 gal., provides pressure. Rapid sand filters supplemented by chlorine treatment. The filters were reconstructed in 1911. Chlorine treatment was begun April, 1919. About 61 miles of mains. The river varies in quality owing to industrial wastes. This necessitates extreme care in the operation of the filter plant. The plant is efficiently operated and although the water sometimes has a disagreeable taste, largely of vegetable origin, a safe sanitary quality of water is maintained. Color 10. Hardness 42. Chlorides 6.

Bar Harbor Water Company.

Supplies a population of about 3 000 in winter and 10 000 in summer. Water works constructed in 1875. The water flows by gravity from a lake. A slow sand filter was installed in 1905 to remove algæ. Forty miles of mains. Color 5. Hardness 16. Chlorides 8. Quality of water excellent.

Bath Water District.

Supplies about 14 731 people. Water is taken from Nequasset Lake and is pumped by electric power to a standpipe, capacity 506 000 gal. The water works was constructed in 1887. Chlorine equipment installed October, 1923. About 32 miles of mains. Color 30. Hardness 23. Chlorides 7. Sanitary quality of water excellent.

Belfast Water District.

Supplies a population of about 5 000. System constructed in 1913. Water is taken from a brook and impounding reservoir and is pumped by electric power, with a steam and a water power auxiliary, to a standpipe, capacity 247 000 gal. Rapid sand filter, also chlorinator which was installed August, 1923. About 12⅔ miles of mains. Color 35. Hardness 28. Chlorides 6. Quite a variation in quality, due to runoff from pastures and cultivated lands. Efficient operation of purification plant produces a safe water but the color is sometimes quite high.

Belgrade Water Company.

Supplies a portion of the town of Belgrade and is a summer supply only. Water is taken from a lake and pumped by electric power to a storage tank, capacity 11 600 gal. Chlorinator installed August, 1923. Three-quarters of a mile of mains. Color 8. Hardness 38. Chlorides 7. Quality of water variable.

Benton.

See Kennebec Water District.

Berwick Water Company.

Supplies a population of about 2 000. Water is taken from springs and wells and pumped by electric power. Chlorinator installed October, 1923. Six miles of mains. Color 11. Hardness 38. Chlorides 7. Quality of water variable.

Bethel Water Company.

Supplies a population of around 1 792. Water flows by gravity from a mountain brook to two covered concrete reservoirs, total capacity 650 000 gal. Seven and one-half miles of mains. Color 10. Hardness 20. Chlorides 4. Sanitary quality of water excellent.

Biddeford & Saco Water Company.

Supplies Biddeford, Saco and Old Orchard, total population 27 000 in winter, 50 000 in summer. The water is pumped by electric power from Saco River to a reservoir, capacity 8 000 000 gal.; and two standpipes, total capacity 675 000 gal. Rapid sand filters installed in 1895 and chlorinator October, 1923. Eighty-three miles of mains. Color 9. Hardness 17. Chlorides 5. The filtered water is of excellent quality.

Bingham Water District.

Supplies a population of 1 143. Water is taken from Jackson Pond and flows by gravity to a distributing reservoir, capacity 450 000 gal. Six and one-quarter miles of pipe line. Color 17. Hardness 32. Chlorides 4. Sanitary quality of water excellent.

See also Landers, E. F.

Blethen House Spring Water Works.

This company supplies a part of the town of Dover-Foxcroft. Water is secured from three springs which are walled up to make storage reservoirs having a capacity of 100 000 gal. Two miles of pipe are in use to convey the water, by gravity, to the consumers. Color 5. Hardness 45. Chlorides 4. Water of excellent quality.

Boothbay Harbor Water Company.

Serves a population of 2 025. Water is taken from a lake and pumped by electric power to a standpipe, capacity 250 000 gal. System constructed in 1894. Chlorinator installed July, 1923. Thirty-five miles of pipe. Color 15. Hardness 28. Chlorides 9. Lake subject to some pollution from agricultural lands. Sterilization by chlorine efficient, producing a water of good quality.

Brewer.

See Penobscot County Water Company.

Bridgton Water and Electric Company.

Serves about 2 500. Water is taken from a lake and pumped by electric power to a standpipe, capacity 392 000 gal. Chlorinator installed September, 1923. Six miles of pipe line. Color 16. Hardness 27. Chlorides 4. Quality of water excellent.

Brooks.

See Consolidated Water Company.

Brownville, Maine, Water Company.

Supplies the village of Brownville in the township of Brownville. The system was installed in 1908. Water flows by gravity from three springs to a reservoir, capacity 25 000 gal. Two and one-half miles of pipe. Color 6. Hardness 29. Chlorides 4. Sanitary quality of water excellent.

Brownville & Williamsburg Water Company.

System constructed in 1908. Supplies Brownville Junction, in the town of Brownville. Population 1 200. Supply taken from springs, auxiliary supply from a small stream, pumped by electric power, to a

storage reservoir, capacity 200 000 gal. Chlorinator installed on auxiliary supply September, 1919. Five miles of mains. Color 30. Hardness 29. Chlorides 4. Spring supply of excellent quality. Auxiliary supply from the stream somewhat colored, but of safe, sanitary quality with chlorine treatment.

Brunswick & Topsham Water District.

Supplies the city of Brunswick and the town of Topsham, serving about 7 000. System constructed in 1886. Water taken from driven wells and pumped by electric power to standpipe, capacity 3 000 000 gal. Chlorinator installed October, 1923. There are about 16 miles of mains. Color 4. Hardness 33. Chlorides 7. Water of excellent quality.

Buckfield Water Company.

Serves a population of 957. System constructed in 1905. Water is taken from a pond and flows by gravity to the mains, of which there are about four miles. Color 9. Hardness 19. Chlorides 4. Water of excellent quality.

Bucksport Water Company.

Supplies a population of 1 906. Gravity supply from a lake. System constructed in 1887. Chlorinator installed March, 1924. Three miles of mains. Color 55. Hardness 33. Chlorides 7. Water is quite high in color with some vegetable tastes. Clogging of screens by eels has been experienced at some seasons of the year. Water is of a fair quality but would probably be improved by filtration.

Calais Water and Power Company.

Supplies a population of 6 084. System installed in 1886. Water is taken from a well owned by the St. Stephens Water Company located about five miles on the Canadian side of the border with the St. Croix River as an auxiliary supply. Water is pumped by electric power to a storage reservoir, capacity 2 500 000 gal. A rapid sand filter and chlorinator (the latter installed January, 1922) are used to purify the auxiliary supply. Twenty-six miles of mains are used. Color 21. Hardness 31. Chlorides 4. Sanitary quality excellent.

Camden & Rockland Water Company.

Supplies the city of Rockland and the towns of Camden and Thomaston. The system was constructed in 1885. Water is taken from a lake by gravity to a distributing reservoir in Rockland, (capacity 2 500 000 gal.) and to a standpipe in Camden (capacity 550 000 gal.). Chlorinator installed November, 1923. Seventy-nine and one-half miles of mains. Color 9. Hardness 17. Chlorides 6. Sanitary quality excellent.

Cape Elizabeth.

See Portland Water District.

Caribou Water, Light and Electric Company.

Supplies a population of 6 018; takes water from the Aroostook River. Water power is used to pump water directly to the mains, the excess going to a standpipe with a capacity of 151 000 gal. Chlorinator installed February, 1920. Seven and one-half miles of mains. Color 36. Hardness 47. Chlorides 5. The river receives some pollution from villages located upstream. The water at times is quite highly colored and also slightly turbid after heavy rains. Chlorine treatment produces a water of safe sanitary quality. At times algæ cause undesirable tastes.

Casco Bay Water Power & Light Company.

See Peak's Island Corporation.

Castine Water Company.

Castine has a population of 743, most of whom are supplied by the Castine Water Company. The water works was built in 1896, taking water from wells and springs. A windmill furnishes power to pump water from three storage reservoirs, total capacity 1 233 000 gal., to a distributing reservoir. Six miles of mains. Color 8. Hardness 47. Chlorides 9. Quality of water excellent.

See also Arcadia Aqueduct Company.

Central Aqueduct Company.

This system was constructed in 1830, and supplies a portion of the village of Skowhegan. Water flows by gravity from three small springs, about one-fourth of a mile of pipe being in use. Color 5. Hardness 59. Chlorides 11. The springs receive some underground drainage from dwellings at a higher elevation but the water is free from bacteria and is considered of safe quality.

Chase, Joseph.

Supplies a portion of the village of Mexico. Original construction 1898. Source, two small springs. Storage reservoir, capacity 12 000 gal. One-quarter of a mile of pipe. Color 5. Hardness 40. Chlorides 8. This supply receives some pollution from dwellings at a higher elevation and is to be abandoned.

Cherryfield Westside Aqueduct Company.

Cherryfield, a town with a population of 1 304, is partially supplied by the Cherryfield Westside Aqueduct Company. The water works was constructed in 1872, water being supplied from wells and springs. One mile of mains. Color 5. Hardness 51. Chlorides 8. Quality of water excellent.

Clement, J. E.

Supplies the village of East Brownfield, population 835. System constructed in 1906. Source of supply, large shallow well. Storage tank, capacity 13 000 gal. Three-fifths of a mile of pipe. Color 8. Hardness 33. Chloride 14. This supply receives undesirable infiltration from dwellings in the vicinity of the well. Water used mostly for flushing and fire protection.

Coburn Aqueduct Company.

Supplies a portion of the village of Skowhegan. Constructed in 1877. Source of supply, two springs. Flows by gravity. Three miles of pipe. Color 12. Hardness 48. Chlorides 14. Conditions very similar to those of Central Aqueduct Company.

Cold Spring Water Company.

Supplies village of Lamoine. Population 327. Installed 1895. Source of supply, spring. Reservoir, capacity 8 000 gal. Three-fifths of a mile of pipe. Color 10. Hardness 25. Chlorides 8. Quality of water excellent.

Columbia Falls.

See Allen, Mrs. M. A.

Consolidated Water Company.

Supplies village of Brooks, population 691. Constructed in 1897. Source of supply, drilled wells 100 ft. deep, also spring. Reservoir, capacity 10 000 gal. Four miles of mains. Color 4. Hardness 47. Chlorides 7. Quality of water excellent.

Cornish Water Company.

System constructed 1911 and supplies population of 813. Supply from springs. Reservoir, capacity 225 000 gal. Nearly four miles of pipe. Color 5. Hardness 23. Chlorides 3. Quality of water excellent.

Crystal Fountain Aqueduct Company.

Supplies a portion of the village of South Paris. System constructed in 1865. Supply from a well. One-eighth of a mile of pipe line. Color 10. Hardness 49. Chlorides 4. Quality of water excellent.

Cumberland Center Water Company.

Supplies the village of Cumberland Center in the town of Cumberland. Original construction 1908. Source of supply, spring. Storage tank, capacity 20 000 gal. Two and one-half miles of pipe. Color 11. Hardness 38. Chlorides 4. Quality of water excellent.

Damariscotta-Newcastle Water Company.

Supplies the towns of Damariscotta and Newcastle. Total population 1 842. The system was constructed in 1896, securing water from a lake. Electric power used to pump the water. Distributing reservoir, capacity 350 000 gal. Seven miles of mains. Color 16. Hardness 19. Chlorides 6. Quality of water excellent.

Danforth Water Company.

Supplies a population of 1 201, taking water from a spring. The system was constructed in 1906. Water pumped by electric power to reservoir, capacity 500 000 gal. One and one-half miles of mains used. Color 23. Hardness 74. Chlorides 6. Springs receive some infiltration from river at times of high water, otherwise of good quality.

Dexter Water Works.

Supplies a population of 4 114. Supply coming from lake. Water is pumped by electric power to reservoir of 500 000 gal. capacity. The system was constructed in 1903. Chlorinator installed November, 1923. Twelve miles of mains. Color 8. Hardness 44. Chlorides 3. Quality of water excellent.

Dixfield Light & Water Company.

Supplies a population of 1 134. System constructed in 1906. Water secured from a mountain brook flowing through wild timber lands. Equalizing and storage reservoir, capacity 500 000 gal. Six miles of mains. Color 32. Hardness 35. Chlorides 4. Quality of water excellent.

Dover-Foxcroft Water District.

Supplies a total population of about 4 000. System constructed in 1888. The original source of supply was the Piscataquis River. Source of supply changed to lake in 1926, the old station being retained in reserve. New supply gravity. Chlorinator installed July, 1918. Storage and equalizing reservoir, capacity 1 500 000 gal. Eight and one-half miles of pipe. Color 29. Hardness 31. Chlorides 4. Quality of water excellent.

See also Blethen House Spring Water Works.

Eastport Water Company.

Serves a populaton of 4 494. Works installed in 1888. Supply from a small river, outlet of lake. Water pumped by water power to storage reservoir, capacity 1 000 000 gal. and equalizing standpipe, capacity 300 000 gal. Chlorinator installed November, 1923. Fifteen miles of mains. Color 33. Hardness 28. Chlorides 7. Water is of good sanitary quality and usually of good appearance, but occasionally contains some organic matter and has a noticeable color.

East Brownfield.

See Clement, J. E.

East Millinocket.

See Northern Water Company.

East Vassalboro Water Company.

System constructed in 1914. Supplies the village of East Vassalboro, in the town of Vassalboro. Water is taken from the outlet of China Lake. Water power used for pumping water to the reservoir from which it flows by gravity. Covered concrete storage reservoir, capacity 40 000 gal. Three-quarters of a mile of mains. Color 10. Hardness 40. Chlorides 4. Water receives some drainage from the village and plans are being made to sterilize the water with hypochlorite of lime.

East Winthrop.

See Augusta Water District.

Ellsworth.

See Penobscot County Water Company.

Eustis Water Company.

Supplies a population of 589. System constructed in 1908. Gravity supply from a spring. Storage reservoir, capacity 25 000 gal. One and three-quarters miles of mains. Color 12. Hardness 24. Chlorides 3. Quality of water excellent.

Fairfield.

See Kennebec Water District and Summit Springs Water Company.

Falmouth.

See Portland Water District.

Farmington Falls Water Company.

Supplies the village of Farmington Falls in the town of Farmington. Constructed in 1909. Source of supply, one spring and a 50-ft. drilled well. Small storage reservoir, no figures available for its capacity. Two and one-half miles of mains. Color 10. Hardness 38. Chlorides 4. Quality of water excellent.

Farmington Village Corporation.

Supplies a population of 3 197. System constructed in 1891. Water flows by gravity from a lake. Standpipe, capacity 250 000 gal. Twenty-one miles of mains. Color 8. Hardness 30. Chlorides 4. Quality of water excellent.

Fort Fairfield.

See Frontier Water Company.

Fort Kent Water Company.

Supplies a population of 4 237. Water flows by gravity from a brook in the hills. System constructed in 1914. Equalizing reservoir, capacity 500 000 gal. Auxiliary supply from Fish River. Chlorinator installed on auxiliary supply July, 1923. Five and one-half miles of mains. Color 29. Hardness 42. Chlorides 4. Main supply of fair quality but insufficient in quantity. Auxiliary supply receives some pollution from villages about five or six miles up the stream.

Freeport Water Company.

Organized in 1891. Supplies a population of 2 488. Water supply from a brook. Electric power used to pump the water. Storage standpipe, capacity 220 000 gal. Chlorinator installed in 1923. Color 18. Hardness 36. Chlorides 8. The color of the water varies at times of heavy rainfall and occasionally has algæ tastes, otherwise it is of good quality.

Friendship Water Company.

Supplies a population of 696 with probably a thousand more in the summer. System constructed in 1897. The supply is taken from springs. Two springs have been dug out to a depth of about 18 ft. and a diameter of 30 ft., walled with field stones. Capacity of these spring reservoirs approximately 600 000 gal. Water is pumped by wind-mill from the reservoirs to a wooden storage tank of about 10 000 gal. capacity. Water has a good appearance but is only of fair quality. Two miles of mains. Color 10. Hardness 44. Chlorides 15.

Frontier Water Company.

Original construction in 1889. Supplies the town of Fort Fairfield. Population 4 551. Main source of supply, spring-fed brook about one-half mile on the Canadian side of the border. Reservoir capacity 1 500 000 gal., located in Canada. Gravity supply. Auxiliary supply, brook, pumped by electric power direct to mains. Chlorine treatment used on auxiliary supply since November, 1921. Five miles of mains. Color 6. Hardness 118. Chlorides 5. Water usually of good quality, but slightly variable.

Fryeburg Water Company.

Supplies a population of 1 283. System constructed in 1882. Water flows by gravity from a mountain stream to a distributing reservoir, capacity 150 000 gal. Chlorinator installed August, 1923. Nine miles of pipe line. Color 8. Hardness 19. Chlorides 3. Deer yarding on the banks of this stream have caused a high bacterial count at times, but the water is usually of good sanitary quality.

Gardiner Water District.

Supplies the city of Gardiner and the town of Randolph. System constructed in 1885. The water, the source of which is Cobbosseecontee Stream, is pumped by water power to a million-gallon reservoir and a standpipe of 350 000 gal. capacity. The purification equipment consists of a slow-sand filter plant of four units and chlorinator, the latter being installed in September, 1923. Twenty-eight miles of mains. Color 13. Hardness 32. Chlorides 4. Quality of water excellent.

Gorham.

See Portland Water District.

Greenville Water Company.

Supplies a total population of 1 550. The water company was organized in 1913. Water flows by gravity from a pond located three miles in the woods on the slope of Squaw Mountain to an equalizing reservoir of 300 000 gal. capacity. Nine and one-half miles of mains are used. Color 37. Hardness 33. Chlorides 4. Quality of water excellent.

See also Hunt, Mrs. Mabel

Grindstone Neck Water Company.

This company supplies the town of Winter Harbor. Total population 503. The water works was installed in 1891. The water is pumped from a pond by steam power to a standpipe of 28 000 gal. capacity. In the winter, Winter Harbor is supplied direct from the pond, but in the summer water is pumped to the standpipe for use in the village of Grindstone Neck. Three and one-half miles of mains. Color 46. Hardness 20. Chlorides 9. Water of excellent quality.

Guilford Water Company.

Supplies a population of 1 687. The works was installed in 1910. Water flows by gravity from a pond to a standpipe of 500 000 gal. capacity. Supplies water to the Sangerville Water Company. Twelve miles of mains. Color 7. Hardness 59. Chlorides 3. Quality of water excellent.

Hallowell Water District.

Supplies a population of 2 764. System constructed in 1898. Water is obtained from an impounded stream and flows through a siphon to a distributing reservoir of 800 000 gal. capacity. A small electric air pump is used to force water over the siphon, the crest of the hill being a few feet higher than the source of supply. Chlorinator installed October, 1923. Seven and one-half miles of mains. Color 16. Hardness 29. Chlorides 6. The water is of good sanitary quality but rather small in quantity. Auxiliary source of supply, Augusta Water District.

Hancock Water, Light & Power Company.

Supplies a population of 770. System constructed in 1885. The source of supply is an abandoned mine. There are four and one-half miles of mains. Color 3. Hardness 159. Chlorides 204. The water is of fair quality.

Harrington.

See Quantabacook Water Company.

Hartland Water Company.

Supplies a population of 1 140. The water works was constructed in 1911. Water is supplied from a pond and flows by gravity direct to the mains. There are 10 miles of mains. Color 18. Hardness 17. Chlorides 4. Quality of water excellent.

Hebron.

This supply, which serves a population of 1 652 was installed in 1900. Water flows by gravity from a pond direct to the mains. There are three and three-quarters miles of pipe line. Color 11. Hardness 17. Chlorides 4. Quality of water excellent.

Hillside Water Company.

Supplies a portion of the village of South Paris. The system was installed in 1860. Source of supply is a shallow well. There is a very small storage reservoir. Three-quarters of a mile of pipe line. Color 6. Hardness 34. Chlorides 4. The water is of excellent quality.

Houlton Water Company.

Supplies a total population of 6 191. The system was installed in 1885. The water is pumped by electric power from a brook to a storage reservoir of 2 100 000 gal. capacity. Chlorinator installed September, 1919. There are 15 miles of mains. Color 33. Hardness 64. Chlorides 4. The water is variable in quality owing to excessive runoff from cultivated lands during heavy rains.

Hunt, Mrs. Mabel.

Supplies a portion of the village of Greenville. The system was installed in 1910. Source of supply is an artesian well. One-half mile of pipe line. Color 7. Hardness 59. Chlorides 3. Quality of water excellent.

Island Falls Water Company.

Supplies a population of 1 683. The system was constructed in 1910. Water is obtained from a brook and is pumped by electric power to a storage reservoir of 500 000 gal. capacity. Chlorinator installed July, 1924. Three and one-half miles of mains. Color 44. Hardness 43. Chlorides 4. Water is highly colored at times and has some vegetable tastes, but otherwise is of good quality.

Jackman Water, Light & Power Company.

Supplies a population of 902. System constructed in 1911. Water is taken from springs and the Moose River and pumped to two reservoirs, total capacity 100 000 gal. Chlorinator installed June, 1921. There are three and one-half miles of mains. Color 36. Hardness 41. Chlorides 4. The water is usually of good quality but somewhat variable.

Jefferson.

See Meserve, James Y.

Kennebec Water District.

This company supplies the city of Waterville, towns of North Vassalboro, Fairfield, Benton and Winslow. Total population about 20 000. Water is obtained from a lake and flows by gravity through North Vassalboro to the city of Waterville. It is then pumped by electric power direct to the mains. There are two storage and equalizing reservoirs with a total capacity of 25 000 000 gal. Chlorinator installed August, 1923. About 50 miles of mains. Color 11. Hardness 31. Chlorides 5. Water of excellent quality.

Kennebunk, Kennebunkport and Wells Water District.

Supplies the towns of Kennebunk, Kennebunkport and Wells. Total population 4 466. System constructed in 1896. Water is pumped by electric power from a brook through pressure type, rapid sand filters, to the mains. There are two standpipes, one with a capacity of 500 000 gal., and the other with a capacity of 229 000 gal. Chlorinator installed April, 1916. Seventy-four miles of mains in use. Color 31. Hardness 36. Chlorides 17. The water has rather a high color at times but otherwise is of good quality.

Kennebunkport.

See Kennebunk, Kennebunkport & Wells Water District.

Kezar Falls Water Company.

Supplies the village of Kezar Falls in the town of Parsonsfield. Total population about 600. The water works was constructed in 1901. Source of supply is a well. Water is pumped by electric power to a storage reservoir, capacity 217 000 gal. Three miles of mains. Color 5. Hardness 22. Chlorides 4. Quality of water excellent.

Kingfield Water Company.

Supplies a population of 975. The water works was constructed in 1897. Water flows by gravity from a mountain stream, outlet of a pond, to an equalizing reservoir of 540 000 gal. capacity. Chlorinator installed December, 1926. There are six miles of mains. Color 17. Hardness 22. Chlorides 4. The water is variable in quality at times of heavy rain but as a rule of excellent quality.

Kittery Water Company.

Supplies a population of 4 763. System constructed in 1908. Water flows by gravity from a lake. Ten and one-half miles of mains. Color 33. Hardness 21. Chlorides 5. The water is of excellent quality.

Lamoine.

See Cold Spring Water Company and Lamoine Beach Water Company.

Lamoine Beach Water Company.

This company supplies about 40 families of the village of Lamoine Beach in the town of Lamoine. The plant was constructed in 1899. Supply taken from a pond. There are two miles of mains. Color 8. Hardness 22. Chlorides 5. Quality of water excellent.

Landers, E. E.

A portion of the town of Bingham is supplied by this company. The system was constructed in 1850. The water is taken from five springs, each one being dug out, walled up, and provided with a wooden roof. The total capacity is 60 000 gal. It is a gravity supply with three miles of mains. Color 6. Hardness 55. Chlorides 3. Quality of water excellent.

Lewiston Water District.

The original construction of the Lewiston Water District supply was in 1878. It serves a population of 31 791. The water flows by gravity from Lake Auburn to the pumping station, a distance of about three miles, and is then pumped by water power direct to the mains, the overflow going to a storage reservoir of 14 000 000 gal. Chlorinator installed November, 1923. There are 65 miles of mains. Color 11. Hardness 24. Chlorides 5. Water is of excellent quality.

Limerick.

See Western Maine Power Company.

Limestone Water & Sewer Company.

Serves a population of 1 506. The system was originally constructed in 1914. It obtains its supply from a brook. The water is pumped by electric power to a storage reservoir of 500 000 gal. capacity. A gasoline engine is used as auxiliary power. Chlorinator installed August, 1926. There are one and one-half miles of mains. Color 18. Hardness 87. Chlorides 7. At times of heavy rainfall this water receives drainage from agricultural lands causing considerable variation in color and turbidity.

Lisbon.

The town of Lisbon, with a population of 4 091, consists of two villages, Lisbon and Lisbon Falls, each with a separate water works but both owned by the town. Both supplies secure water from shallow driven wells. Color 5. Hardness 73. Chlorides 8. Quality of water excellent.

Lisbon Falls.

See Lisbon.

Livermore Falls Water District.

Supplies the village of Livermore Falls in the town of East Livermore. Population about 2 000. System originally constructed in 1900. The water flows by gravity from a pond to a storage reservoir of 1 000 000 gal. capacity. Two-pressure system, water being pumped from the low pressure section to the high. Chlorinator installed October, 1923. Nine miles of mains. Color 8. Hardness 23. Chlorides 4. Quality of water excellent.

Lincoln Water Company.

Supplies a population of 2 452. System installed in 1912. The water flows by gravity from a pond to a storage reservoir of 500 000 gal. capacity. A river is used as an auxiliary supply. Chlorinator installed on the auxiliary supply November, 1924. There are 10 miles of mains. Color 30. Hardness 18. Chlorides 3. Quality of water excellent.

Long Pond Water Company.

Supplies the village of Sorrento. Population 140. Water works originally constructed in 1886. It is a gravity supply and the source is a pond. Six miles of pipe line. Color 16. Hardness 13. Chlorides 5. Quality of water excellent.

Lubec Water Works.

Originally constructed in 1902. Serves a population of 3 371. Water is obtained from springs and wells. Steam and electric power are used for pumping. There are two storage reservoirs located near the wells with a total capacity of 1 000 000 gal. and a standpipe of 300 000 gal. capacity located in the town. Chlorinator installed August, 1920. There are seven miles of pipe. Color 13. Hardness 86. Chlorides 16. The water is variable in quality.

Machias Water Company.

Serves a population of 2 152. System constructed in 1896. Water is obtained from a river, and steam and electric power are used to pump it to a pressure standpipe of 350 000 gal. capacity. Chlorinator installed January, 1920. Six miles of mains. Color 69. Hardness 19. Chlorides 6. This water has rather a high color and some vegetable tastes. Considerable changes are noted at times of heavy rainfall.

Madison Water District.

Has a population of 3 700. Water works installed in 1891. In 1906 the source of water was changed from a river to a pond. The water flows by gravity to a storage reservoir of 600 000 gal. capacity. This company also supplies the Anson Water Company. There are 30½ miles of pipe line. Color 17. Hardness 20. Chlorides 4. Water of excellent quality.

Manchester.

See Augusta Water District.

Mars Hill Water Company.

Supplies a population of 1 783. The system was constructed in 1911. The water flows by gravity from a lake to a storage reservoir of about 500 000 gal. capacity. There are seven miles of pipe line. Color 15. Hardness 77. Chlorides 4. Quality of water excellent.

Mechanic Falls Water Company.

Supplies a population of 1 614. System constructed in 1895. Water is taken from a brook, steam and electric power being used to pump it to a standpipe of 318 000 gal. capacity. Rapid sand filters are in use and all the water has been sterilized with chlorine since 1919. Six and one-half miles of mains. Color 15. Hardness 35. Chlorides 5. Quality of water excellent.

Meserve, James Y.

This company supplies a portion of the village of Jefferson. The system was installed in 1903 and is a gravity supply from a spring. There are one and one-half miles of mains. Color 6. Hardness 41. Chlorides 4. Quality of water excellent.

Mexico Water Company.

Supplies most of the town of Mexico, which has a total population of 3 242. System constructed in 1908. The main supply comes from a brook and flows by gravity to two storage reservoirs with a total capacity of 3 000 000 gal. The auxiliary supply consists of two shallow wells located on the river bank. This supply is pumped by electric power to the reservoirs. Chlorinator installed November, 1926. Five miles of mains. Color 19. Hardness 32. Chlorides 4. Quality of water somewhat variable.

See also E. A. Abbot Water Company, Chase, Joseph, and Rumford and Mexico Water District.

Milbridge Water Company.

Supplies a population of 1 196. The system was installed in 1878. Water is taken from springs and wells and flows to a reservoir of 30 000 gal. capacity. Two and three-quarters miles of mains. Color 6. Hardness 27. Chlorides 9. Water of excellent quality.

Milford.

See Penobscot County Water Company.

Millinocket Water Company.

Serves a population of 4 528. The system was constructed in 1901. Water is supplied from a lake and is pumped by electric power. Rapid sand filters are in use. Seven and one-half miles of mains. Color 32. Hardness 23. Chlorides 4. The water is somewhat variable, but usually of excellent quality.

Milo Water Company.

Serves a population of 2 894. System originally constructed in 1909. Water is pumped by electric power from a stream, which is the outlet of a large lake, to a reservoir of 400 000 gal. capacity. Chlorinator installed August, 1920. Five and one-half miles of mains. Color 27. Hardness 17. Chlorides 3. The water varies in color at times, due to drainage from swamps and timber lands, but otherwise is of good quality.

Monhegan Water Company.

Supplies a population of 133. System installed in 1914. The water is pumped by a gas engine from a drilled well, 38 to 48 ft. deep, to a storage reservoir of 13 000 gal. capacity. One mile of mains. Color 5. Hardness 92. Chlorides 35. Water of excellent quality.

Monson Spring Water Company.

Supplies a portion of the village of Monson, which has a total population of 1 079. The sources of supply are: one drilled well 350 ft. deep; one drilled well 125 ft. deep, and one spring. There are two storage reservoirs with a total capacity of 800 000 gal. One and three-quarters miles of mains. Color 5. Hardness 27. Chlorides 5. Quality of water excellent.

Morrill Water Company.

Supplies a population of 307. The system was installed in 1907. The water is obtained from an artesian well, 70 ft. deep and the source of power is a windmill. There is a storage reservoir with a capacity of 10 000 gal. Three-quarters of a mile of mains. Color 4. Hardness 74. Chlorides 9. The water is of excellent quality.

National Soldiers Home.

See Augusta Water District.

Newcastle.

See Damariscotta-Newcastle Water Company.

Newport Water Company.

Serves a population of 1709. System installed in 1894. The water flows by gravity from a lake to two storage reservoirs having a total capacity of 2 000 000 gal. One of these reservoirs, of approximately 500 000 gal. capacity, is maintained for fire protection only and water is pumped to it from the main system by electric power. Chlorinator installed May, 1926. Six miles of mains. Color 33. Hardness 51. Chlorides 6. The water is slightly variable in quality.

New Sharon Water Company.

Supplies a population of 885. System constructed in 1911. The main source of supply is a flowing, driven well, 30 ft. deep. The water flows from the well to the storage reservoir of 100 000 gal. capacity and then to the mains. An auxiliary supply is taken from the Sandy River and pumped by electric power. Hypochlorite treatment was installed on the auxiliary supply in July, 1926. There are two and one-half miles of mains. Color 14. Hardness 55. Chlorides 5. The main supply is excellent in quality but lacking in quantity. The auxiliary supply is variable in quality.

Norridgewock Water Company.

Supplies a portion of the village of Norridgewock. Total population 1 532. The system was constructed in 1912. The water is obtained from a spring and a brook and flows by gravity to a storage reservoir of 1 500 gal. capacity. One mile of mains. Color 7. Hardness 51. Chlorides 9. The water is not of the best quality owing to drainage from dwellings at a higher elevation than the spring.

North Anson.

See Anson Water District.

North Berwick Water Company.

Supplies a total population of 1 652. System installed in 1896. The water is pumped by electric power to a standpipe with a capacity of 200 000 gal. A rapid sand filter improves the appearance of the water. Chlorinator installed March, 1919. Five and three-fifths miles of mains. Color 31. Hardness 33. Chlorides 6. The water varies in color at different times of the year but usually is of good quality.

North Bridgton Water Company.

Supplies the village of North Bridgton in the town of Bridgton. The system was installed in 1910 and is a gravity supply from a spring. About two miles of mains. Color 7. Hardness 27. Chlorides 4. Water of excellent quality.

Northeast Harbor Water Company.

Supplies the village of Northeast Harbor in the town of Mt. Desert. The plant was constructed in 1883. Water is pumped from a pond to a standpipe of 124 000 gal. capacity. Seven miles of mains. Color 15. Hardness 21. Chlorides 8. Quality of water excellent.

Northern Water Company.

Supplies the town of East Millinocket. Population 1 392. The system was installed in 1908. Water is taken from artesian wells. The Penobscot River is used as an auxiliary supply. Electric power is used to pump the water to a standpipe of 375 000 gal. capacity. Chlorinator installed September, 1924. Six miles of mains. Color 28. Hardness 33. Chlorides 5. The water is somewhat variable but usually of good quality.

North Haven Water Company.

Supplies the village of North Haven in the town of North Haven. Total population 510. System constructed in 1911. Source of supply is a pond. There is a standpipe with a capacity of 250 000 gal. Eight miles of mains. Color 37. Hardness 34. Chlorides 12. The water varies in color but otherwise is of good quality.

Northport Mountain Spring Company.

Supplies the village of Northport in the town of Northport. Population 466. System installed in 1891. Water is obtained from springs. Three miles of pipe line. Color 2. Hardness 65. Chlorides 8. Water of excellent quality.

North New Portland.

See North Village Water Company.

North Vassalboro.

See Kennebec Water District.

North Village Water Company.

Supplies the village of North New Portland in the town of New Portland. Population 840. The water works was installed in 1906. The water flows by gravity from a spring to a storage reservoir of 150 000 gal. capacity. Two miles of pipe. Color 5. Hardness 30. Chlorides 4. Quality of water excellent.

Norway Water Company.

Serves a population of 2 969. System constructed in 1886. Water pumped by electric power from a lake to a reservoir of 500 000 gal. capacity. Chlorinator installed June, 1923. Five miles of mains. Color 20. Hardness 28. Chlorides 4. Quality of water excellent.

Oakland Water Company.

Serves a population of 2 473. System installed in 1889. Water pumped by electric power from a lake to a reservoir of 1 000 000 gal. capacity. Chlorinator installed October, 1923. Four and one-half miles of mains. Color 16. Hardness 29. Chlorides 4. Quality of water excellent.

Old Orchard.

See Biddeford and Saco Water Company.

Oldtown.

See Penobscot County Water Company.

Orono.

See Penobscot County Water Company.

Paris Hill Water Company.

Supplies a portion of the village of South Paris. Water is taken from wells. Three miles of mains. Color 6. Hardness 31. Chlorides 4. Water of excellent quality.

Patten Water Company.

Supplies a total population of 1 498. The system was installed in 1893. Water flows by gravity from a spring to a reservoir of 9 500 gal. capacity. An artesian well, 60 ft. deep is used as an auxiliary supply. One and one-quarter miles of mains. Color 9. Hardness 92. Chlorides 7. The water is usually of good quality.

Peaks Island Corporation.

Was recently changed to the Casco Bay Water, Light and Power Company. The water works was constructed in 1910 and supplies a portion of the city of Portland. In the summer, water is secured from the Portland Water District. In the winter it is taken from four drilled wells from 200 to 250 ft. deep. Oil is used as power for pumping. Eight miles of mains. Color 7. Hardness 51. Chlorides 19. Water of excellent quality.

Penobscot County Water Company.

Ellsworth — this company supplies a population of 3 058. Plant constructed in 1888. Water is pumped by electric power from the outlet of a lake to a standpipe of 301 000 gal. capacity. Chlorinator installed July, 1923. There are 13.2 miles of mains. Color 39. Hardness 23. Chlorides 5. Water varies somewhat in color but usually is of excellent quality.

Oldtown — Population 6 966. This system was constructed in 1889. Supplies the city of Oldtown and the village of Milford. Water is pumped by electric power from the Penobscot River. Pressure type, rapid sand filters are used for improving the appearance of the water. Chlorinator installed January, 1920. Twenty-three and five-tenths miles of mains. Color 39. Hardness 31. Chlorides 9. The water is variable in quality and sometimes has a considerable amount of vegetable tastes, usually however, it is of good quality.

Orono — Population 9 700. This system was constructed in 1888. Supplies the city of Brewer and the towns of Orono and Veazie. The water flows by gravity from a lake, through a syphon under the Penobscot River, to the pumping station, and is then pumped by electric power to the distributing system. There are two standpipes with a total capacity of 924 000 gal. Chlorinator installed October, 1923. A coarse gravel filter is used at the intake to keep out leaves, floating sticks and other coarse material. Thirty-nine and four-tenths miles of pipe. Color 44. Hardness 29. Chlorides 5. The water is rather highly colored and has some swampy tastes at times, but otherwise is of excellent quality.

People's Water Company.

Supplies a portion of the village of South Paris. Water is obtained from a well. Two miles of mains. Color 10. Hardness 39. Chlorides 4. Water of excellent quality.

Phillips Water Company.

Serves a population of 1 353. The system was installed in 1898. It is a gravity supply from a pond located on the slope of Mt. Blue. There is a storage and equalizing reservoir with a capacity of 500 000 gal. Eight miles of mains. Color 24. Hardness 21. Chlorides 4. The water is slightly colored owing to drainage from wild land but otherwise is of excellent quality.

Pine Tree Aqueduct Company.

Supplies a portion of the village of South Paris. The works was installed in 1879. Water is taken from six drilled wells. Two and one-half miles of mains. Color 7. Hardness 54. Chlorides 4. Water of excellent quality.

Pittsfield Water Works.

Serves a population of 2 700, was constructed in 1894. The source of supply is four wells which are located along the bank of a stream. Electric power is used to pump the water to a standpipe of 365 000 gal. capacity. Chlorinator installed November, 1923. Eleven miles of mains. Color 10. Hardness 60. Chlorides 9. Water of excellent quality.

Port Clyde.

See St. George Water Company.

Portland Water District.

Supplies the cities of Portland, South Portland, and the towns of Cape Elizabeth, Scarboro, Westbrook, Gorham and Falmouth. Total population 90 000. The water works was constructed in 1868. Water is obtained from Sebago Lake and flows by gravity to five standpipes having a total capacity of 2 650 000 gal. There are three reservoirs with a total capacity of 40 000 000 gal. Chlorinator installed April, 1921. Three hundred fifty-six and three-tenths miles of mains. Color 11. Hardness 22. Chlorides 4. Water of excellent quality.

Presque Isle Water Company.

Serves a population of 5 581. The system was installed in 1887. Water comes from a stream and a brook and is pumped by electric power to a reservoir of 1 500 000 gal. capacity. Chlorinator installed February, 1918. Twelve miles of mains. Color 20. Hardness 106. Chlorides 9. The water is variable in quality owing to drainage from agricultural lands.

Quantabacook Water Company.

Supplies the town of Harrington. Population of 1 860. The water flows by gravity from a spring to a reservoir of 50 000 gal. capacity. Five miles of mains. Color 5. Hardness 43. Chlorides 7. Water of excellent quality.

Randolph.

See Gardiner Water District.

Rangeley Water Company.

Supplies a population of 1 028. The works was constructed in 1905. Water flows by gravity from a mountain stream to an equalizing reservoir of 450 000 gal. capacity. Eight miles of mains. Color 38. Hardness 20. Chlorides 3. This water varies somewhat owing to drainage from wild timber lands but is generally of excellent quality.

Richmond Water Works.

Installed in 1884 and serves a population of 1 724. The water is pumped by electric power from the Kennebec River through pressure-type, rapid sand filters to the distribution system. There is a storage reservoir of 1 000 000 gal. capacity. Chlorinator installed March, 1921. Seven miles of pipe line. Color 27. Hardness 34. Chlorides 6. The water is somewhat variable in quality owing to mill wastes in the river and sewage from communities up stream. Excellent results have been obtained with the purification system and although the water occasionally has unpleasant tastes and odors and is somewhat colored, yet it is maintained in a safe condition by the use of chlorine treatment.

Roberge, Joseph.

This company supplies a portion of the village of South Berwick. It is a gravity supply from a spring. One-half mile of pipe line. Color 5. Hardness 40. Chlorides 8. Water of excellent quality.

Rockland.

See Camden & Rockland Water Company.

Rumford & Mexico Water District.

Supplies a population of 8 576. The system was constructed in 1893. Water flows by gravity from a brook to four storage reservoirs with a total capacity of 114 000 000 gal. An auxiliary source of supply is a brook on which a chlorinator was installed in 1923. This is not in use at the present time. Twenty-one miles of mains. Color 22. Hardness 25. Chlorides 4. Quality of water excellent.

See also Smith and Greene Water Company.

Saco.

See Biddeford and Saco Water Company.

Sanford Water Company.

Serves a population of 10 691. The system was installed in 1887. Water is pumped by electric power from twelve shallow driven wells and five springs located near the Mousam River. There is a storage reservoir of 830 000 gal. capacity. Chlorinator installed, 1923. Fifteen and one-half miles of mains. Color 10. Hardness 57. Chlorides 3. Water of excellent quality.

Sangerville Water Company.

Serves a population of 1 246. System constructed in 1910. Water is secured from the Guilford Water Company and pumped to a storage standpipe with a capacity of 500 000 gal. Five and one-half miles of pipe.

Scarboro Water Company.

Supplies a population of 1 832. The works was installed in 1899. Water is secured from the Portland Water District.

Seal Harbor Water Company.

Supplies the village of Seal Harbor in the town of Mt. Desert. The system was constructed in 1900. It is a gravity supply from a lake. Six miles of mains. Color 9. Hardness 18. Chlorides 8. Quality of water excellent.

Searsport Water Company.

Supplies a population of 1 373. System constructed in 1906. The water is obtained from the Stockton Springs Water Company. Flows by gravity to a storage reservoir, capacity 300 000 gal. A spring is used as an auxiliary supply. Ten miles of mains. Color 12. Hardness 22. Chlorides 4. Quality of water excellent.

Skowhegan Aqueduct Company.

Supplies a portion of the village of Skowhegan. Works constructed in 1836. The water flows by gravity from five small springs. There are two miles of mains. Color 12. Hardness 43. Chlorides 13. The water is somewhat variable in quality owing to drainage from dwellings located at a higher elevation than the springs.

See also Central Aqueduct Company, Coburn Aqueduct Company, Skowhegan Water Company and West Skowhegan Aqueduct Company.

Skowhegan Water Company.

Supplies the greater part of the village of Skowhegan. Population 5 981. System installed in 1836. Water is pumped by electric power from a storage reservoir, which is supplied by springs. One reservoir, capacity 250 000 gal. One new reservoir, no figures available. Standpipe of 270 400 gal. capacity. Auxiliary supply Kennebec River. Chlorinator installed February, 1918. Twelve miles of mains. Color 24. Hardness 35. Chlorides 7. Water varies a little with the seasons but usually is of excellent quality.

See also Central Aqueduct Company, Coburn Aqueduct Company, Skowhegan Aqueduct Company and West Skowhegan Aqueduct Company.

Small Point Water Company.

Supplies the summer colony of Small Point in the town of Phippsburg. The plant was installed in 1893. Water is pumped by electric power from a pond to a storage tank, capacity 50 000 gal. Chlorinator installed May, 1926. About two miles of mains. Color 102. Hardness 36. Chlorides 19. Water quite variable in color and has vegetable tastes at times but otherwise of good quality.

Smith & Greene Water Company.

Supplies about 50 houses in the town of Rumford. The system was installed in 1908. Obtains water from a spring. There is a storage reservoir of 84 000 gal. capacity located at the spring. One half mile of pipe. Color 11. Hardness 28. Chlorides 5. The quality of the water is fair but could be made of excellent quality by proper protection.

Sorrento.

See Long Pond Water Company.

South Berwick Water Company.

Serves a population of 2 955. System constructed in 1893. Water is secured from a river and pumped by electric power to a storage reservoir, capacity 500 000 gal. Chlorinator installed July, 1921. Six and one-half miles of mains. Color 46. Hardness 35. Chlorides 6. Water is somewhat variable in quality.

See also Roberge, Joseph.

South Freeport Water Company.

Supplies the village of South Freeport in the town of Freeport. The supply is obtained from a well. About two miles of mains. Color 6. Hardness 40. Chlorides 7. Quality of water excellent.

South Paris Village Corporation.

This is the main supply for the village of South Paris, which has a total population of 3 656. The plant was installed in 1909 and is a gravity supply from a brook. The water flows to two storage reservoirs having a total capacity of 1 500 000 gal. Chlorinator installed, 1921. Eight miles of pipe line. Color 31. Hardness 29. Chlorides 5. The water is somewhat variable in quality due to drainage from agricultural lands.

See also Crystal Fountain Aqueduct Company, Hillside Water Company, Paris Hill Water Company, People's Water Company and Pine Tree Aqueduct Company.

Southport Water System.

This system was constructed in 1923 and supplies the village of Southport which has a permanent population of 272. This is a summer supply only at which time the population is approximately 3 000. The water is pumped by electric power from a pond to a standpipe of 60 000 gal. capacity. Five miles of mains, practically all on the surface. Color 66. Hardness 18. Chlorides 12. The water is quite highly colored and somewhat variable in quality. Probably could be improved by filtration.

South Portland.

See Portland Water District.

Southwest Harbor Water Company.

Serves a population of 824. The system was installed in 1893. Water is obtained from a pond and flows to a standpipe. Seven miles of mains. Color 13. Hardness 16. Chlorides 8. Quality of water excellent.

Springvale Aqueduct Company.

Supplies the village of Springvale in the town of Sanford. The system was constructed in 1878. Water flows by gravity from a pond. A slow sand filter is used. Chlorinator installed in the summer of 1924. An auxiliary supply is obtained from the Mousam River. This is also chlorinated. There are seven miles of mains. Color 13. Hardness 26. Chlorides 4. The water is somewhat variable in quality but usually very excellent.

Stratton Water Works.

Installed in 1900. Supplies the village of Stratton in the town of Eustis. Water flows by gravity from a spring to a small reservoir. Two miles of mains. Color 8. Hardness 34. Chlorides 4. Water of excellent quality.

Steep Falls Water Company.

Plant constructed in 1907. Supplies the village of Steep Falls in the town of Standish. Water is pumped by a windmill from a spring to a small elevated tank of 1 200 gal. capacity. One-half mile of mains. Color 11. Hardiness 36. Chlorides 5. The water is somewhat variable in quality but usually excellent.

St. George Water Company.

Supplies the village of Port Clyde in the town of St. George. Works installed in 1909. The source of supply is a drilled well, approximately 180 ft. in depth. The water is pumped to a standpipe of 70 000 gal. capacity. Three miles of mains. Color 16. Hardness 65. Chlorides 25. The water is somewhat variable but generally of good quality.

St. Stephens Water Company.

See Calais Water and Power Company.

Stockton Springs Water Company.

Serves a population of 1 173. The system was installed in 1906. The water flows by gravity from a lake to a storage reservoir of 400 000 gal. capacity. Fourteen miles of mains. Color 11. Hardness 30. Chlorides 5. Water of excellent quality.

Stonington Water Company.

Serves a population of 1 353. Obtains its water from a pond. Water is pumped by a kerosene engine from the pond to a storage reservoir of 350 000 gal. capacity. Hypochlorite treatment begun in July, 1926. Two and one-half miles of mains. Color 105. Hardness 21. Chlorides 13. The water is highly colored and has some vegetable tastes but otherwise is of good quality.

Strong Water District.

Supplies a population of 779. System constructed in 1903. The water flows by gravity from a pond to a storage reservoir of 500 000 gal. capacity. Chlorinator installed January, 1927. Six miles of mains. Color 47. Hardness 41. Chlorides 4. The water is somewhat variable but usually of excellent quality.

Sullivan Harbor Water Works.

Installed in 1905. Gravity supply from a pond. Three-quarters of a mile of mains. Color 25. Hardness 26. Chlorides 8. Quality of water excellent.

Summit Springs Water Company.

Supplies a portion of the village of Fairfield. The water flows by gravity from 12 small springs to a storage reservoir of 15 000 gal. capacity. About three miles of pipe line. Color 7. Hardness 66. Chlorides 4. Water somewhat variable in quality.

Thomaston.

See Camden and Rockland Water Company.

Topsham.

See Brunswick & Topsham Water District.

Union Water Company.

Supplies the village of Union. Total population 1 133. System constructed in 1895. Water is obtained from an artesian well and flows to a reservoir of 250 000 gal. capacity. One and one-quarter miles of pipe line. Color 10. Hardness 26. Chlorides 6. Water of excellent quality.

Van Buren Water District.

Supplies a population of 4 594. The works was installed in 1903. The water flows by gravity from a brook. Water for fire purposes is pumped to a storage reservoir by a gasoline engine. The reservoir has a total capacity of 500 000 gal. Chlorinator installed March, 1923. Nine and one-half miles of mains. Color 24. Hardness 65. Chlorides 4. The water varies in quality a little at times of heavy rainfall but is usually excellent.

Vassalboro.

See East Vassalboro Water Company.

Veazie.

See Penobscot County Water Company.

Vinalhaven Water Company.

Serves a population of 1 965. Plant installed in 1909. The water is pumped by electric power from a pond to a standpipe of 318 000 gal. capacity. Six and one-half miles of mains. Color 74. Hardness 20. Chlorides 12. The water is usually quite highly colored but otherwise is of good quality.

Waldoboro Water Company.

Supplies a population of 2 426. The system was constructed in 1910. Water is pumped by windmills from artesian wells to a reservoir of 2 000 000 gal. capacity. Three and one-half miles of pipe line. Color 8. Hardness 34. Chlorides 6. Water of excellent quality.

Warren Water Company.

Serves a population of 1 500. System installed in 1897. The water is obtained from a well and spring and flows by gravity to a reservoir of 1 000 000 gal. capacity. Two miles of pipe line. Color 15. Hardness 44. Chlorides 8. Quality of water excellent.

Washburn Water Company.

This system was constructed in 1917. Supplies a population of 1 870. The water is pumped by electric power from three artesian wells to a storage reservoir of 1 000 000 gal. capacity. Two and one-half miles of pipe. Color 5. Hardness 161. Chlorides 11. Quality of water excellent.

Waterville.

See Kennebec Water District.

Weeks Mills Water Company.

Supplies the village of Weeks Mills in the town of China. The plant was constructed in 1909. Water is obtained from a spring. It is pumped by a windmill to a reservoir with a capacity of 10 000 gal. One mile of mains. Color 8. Hardness 79. Chlorides 6. The water is variable in quality due to drainage from agricultural lands.

Wells.

See Kennebunk, Kennebunkport & Wells Water District.

Westbrook.

See Portland Water District.

West Falmouth Water Company.

Supplies the village of West Falmouth in the town of Falmouth. The system was installed in 1910. Water is secured from a spring and flows by gravity to a reservoir of 2 000 gal. capacity. One mile of pipe line. Color 7. Hardness 61. Chlorides 11. Quality of water excellent.

Western Maine Power Company.

Supplies the town of Limerick. Population of 761. The system was constructed in 1908. Water is taken from springs and artesian wells and is pumped by electric power to a storage reservoir of 275 000 gal. capacity. Chlorinator installed September, 1926. One and three-quarters miles of mains. Color 9. Hardness 34. Chlorides 4. Water of excellent quality.

Westfield Electric Company, Mars Hill.

Supplies the village of Westfield. Population of 798. Plant constructed in 1910. The water flows by gravity from a spring and a brook to a reservoir with a capacity of 1 000 000 gal. Hypochlorite treatment begun December, 1926. One mile of pipe line. Color 19. Hardness 174. Chlorides 7. The water is variable in quality owing to drainage from agricultural lands.

West Skowhegan Aqueduct Company.

Supplies a portion of the town of Skowhegan. The system was constructed in 1836. Water flows from four springs by gravity to a reservoir of 2 350 gal. capacity. Chlorinator installed September, 1925. Three-quarters of a mile of mains. Color 7. Hardness 49. Chlorides 14. The water is somewhat variable in quality owing to drainage from dwellings at a higher elevation than the springs.

Wilton Water Works.

Installed in 1897. Serves a population of 2 505. The water is pumped by electric power from a pond to two storage reservoirs having a total capacity of 800 000 gal. Fifteen miles of pipe line. Color 7. Hardness 37. Chlorides 3. Quality of water excellent.

Winslow.

See Kennebec Water District.

Winter Harbor.

See Grindstone Neck Water Company.

Winterport Water Company.

Supplies a population of 1 433. The system was constructed in 1896. Water is pumped by electric power from a brook to a standpipe of 200 000 gal. capacity. Chlorinator installed July, 1923. Three and one-half miles of main. Color 16. Hardness 52. Chlorides 6. The water varies in quality but is usually excellent.

Winthrop Water Company.

Supplies a population of 1 902. Plant installed in 1925. The water is pumped by electric power from a lake to a standpipe of 200 000 gal. capacity. Chlorinator installed April, 1925, as a part of the original construction. Two miles of mains. Color 14. Hardness 27. Chlorides 6. Water of excellent quality.

Wiscasset Water Company.

Supplies a population of 1 192. System was installed in 1916. The water is pumped by electric power from a brook to a storage reservoir of 700 000 gal. capacity. Pressure type, rapid sand filters were installed in 1920 and a chlorinator, July, 1923. Four miles of mains. Color 18. Hardness 31. Chlorides 8. The water varies in quality at times of heavy rainfall but is usually good.

Woodland Water Company.

Supplies the village of Woodland in the town of Baileyville. Population of 1 120. The system was constructed in 1906. Water is obtained from the St. Croix River. There is a standpipe with a capacity of 75 000 gal. Pressure type, rapid sand filters and chlorinator were installed in 1922. About three miles of mains. Color 16. Hardness 26. Chlorides 5. The water is somewhat variable in quality but usually excellent.

Yarmouth Water Company.

Supplies the village of Yarmouthville in the town of Yarmouth. The system was constructed in 1895. Secures water from springs. The water flows by gravity to a standpipe of 265 000 gal. capacity. The auxiliary supply is pumped by electric power from a river. Chlorinator installed September, 1920. Twenty miles of mains. Color 5. Hardness 44. Chlorides 7. Quality of water excellent.

Yarmouthville.

See Yarmouth Water Company.

York Shore Water Company.

Supplies York Village in the town of York. Population 2 727. The works was constructed in 1896 and secures water from a lake. Thirty-five and one-half miles of mains. Color 18. Hardness 19. Chlorides 8. Water of excellent quality.

MILITARY AND EMERGENCY WATER SUPPLIES.

BY GEORGE C. DANFORTH.*

[*Read December 8, 1926.*]

INTRODUCTION.

It may be pertinent to give some of the reasons why "Military Water Supply" has been chosen as a subject of interest to civilian engineers and water-works men. "The War is over" is a remark often heard these days, even in New England. And New England supplied more men in 1917–1918, and more casualties in proportion to the population than any other section of the country. We said the same thing after the Spanish War and after the Philippine Insurrection.

In the last war, although there was ample warning, we refused to prepare before it came and it was over a year before we had one partially-trained division on an active front. After it was over our memory of past experience was sufficient to bring the National Defense Act of 1920, the first indication in our history that we considered war a future possibility. We were willing to outline a framework on which an army could be fashioned, although the law was almost as non-militaristic as the professional pacifist could wish.

The Congress has not, however, seen fit to provide even the small appropriations necessary for the conservative program of that Act. This reduction of appropriations to below the absolute minimum required is due to the fact that the electorate is uninterested or lacks information or has been intentionally misinformed. It is also partly due to the fact that the conservative element of the electorate has not the habit of writing letters to its Congressmen. The radical element has that habit as well as other means of impressing its point of view on Congress. It is, therefore, of some importance that civilians be informed in a general way as to the army program and be able and willing to express opinions which can be heard in Washington, particularly in regard to the continued reduction in the regular army and the failure to provide for proper maintenance of the Reserve Corps, the latter being especially important to those branches which have to draw on trained men from civil life in an emergency. The special water-supply troops are in this class.

This paper will discuss some of the problems connected with the supply of water for an army in the field and the organization developed by the United States Army for handling them. Attention may be called to the fact that here the words "military" and "emergency" are synonymous and the methods discussed apply as well to the needs of agriculturists.

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explorers and those who may find emergency supplies necessary in their civil experience. The breaking of the mains in San Francisco in 1906 was a sample of such an emergency.

Modern views of sanitation impose severe restrictions. The difficulties in connection with the enormous size of modern armies, the contamination of surface supplies through long occupation of restricted areas by large numbers of men and animals, and the destruction and fouling of wells by enemy troops, introduce new factors. To furnish pure water to a city of 50 000 or 100 000 population is not a simple task. What of the task in supplying that number of men who have moved into an uninhabited area on one or two days' notice?

The material discussed is divided into the following sections:

I. Organization, Equipment, and Duties.
II. Water Supply in Mobile and Stabilized Warfare.
III. Sources of Supply.
IV. Hydraulics.
V. Development of Supply.
VI. Purification.

Much of the material included may be classed as elementary, in particular, the section on hydraulics. Here an attempt has been made to include only that minimum necessary for the solution of such problems as are likely to occur. The section on the quality of water is not meant to outline methods of analysis but to permit a reasonable interpretation of analyses made by others.

The writer has had the opportunity during the past year of preparing the manual on water supply for the United States Army, to be published as Training Regulations 445–150, Water Supply, and certain material in that publication has been used in this paper.

Some of the reference material available is listed at the end of the paper, including the extremely valuable reports on American experience in France available in manuscript in the office of the Chief of Engineers of the Army. It should be noted, however, that reports on conditions in France were based on a stabilized situation which cannot be considered as normal for American forces. Future wars in which we may be involved are likely to bring conditions of mobile or open warfare which existed in France only before the first Battle of the Marne and after November 1, 1918. From this point of view the experience of the British in Egypt, Palestine, Mesopotamia and Macedonia is of great interest and value.

I. Organization, Equipment, and Duties.

Duties of Engineer Troops. The smallest unit to which engineer troops are normally assigned is the Division. The Combat Engineer Regiment assigned to the Infantry Division is charged with all engineer work at the front, normally reconnaissance, roads and bridges, trench lay-outs and

shelters, and the water supply of the division when this has not been provided by higher units. Abnormally, and incorrectly, except under conditions of great danger, it has been used as Infantry.

The next higher unit, the Corps, has assigned to it one General Service Engineer Regiment. Its duties include general construction work in the Corps area, roads and bridges in rear of the Combat Regiment, light railways and such water-supply work as is not taken over by the Division or handled directly by army troops. The Corps Engineer is also responsible for the distribution of engineer supplies to corps troops.

The largest tactical unit, the Army, is responsible for water-supply installation, operation and maintenance not taken over by Corps or Division Engineers, and for all geological investigations. Three General Service Engineer Regiments and one Engineer Water-Supply Battalion are normally assigned to the Army and there is assigned to General Headquarters Reserve, one Water-Supply Battalion for each Field Army in the Expeditionary Force.

In general, it may be stated that the responsibility for the quality of water supplied to troops in the theatre of operations rests with the engineers (assisted as may be necessary for laboratory examination by attached Medical Department personnel) to include delivery to the water point. The handling of water in the organization water cart, in the sterilizing bag, and in the canteen of the individual soldier is a responsibility of the unit commander with the advice and assistance of attached medical personnel.

Duties of the Engineer Water-Supply Battalion include providing the special equipment necessary for water supply activities in the theatre of operations, the operation of tank and purification trucks and the furnishing of expert advice and reconnaissance. It operates under the appropriate unit engineer either as a unit or in separate detachments, and the personnel necessary for construction is drawn from engineer general troops. The Battalion with all mobile equipment is normally assigned to forward areas, and is organized as follows:

	Officers	Men	Tank Trucks	Purification Trucks
Three companies of four officers, 160 men each	12	480	150	
Battalion headquarters and headquarters and service platoon	6	80	...	12
	18	560	150	12
Attached Medical Department	7	30	...	...

Equipment. The water-supply equipment of the Division and Corps is designed to furnish means for establishing local points at which water carts may be filled. The equipment includes (Cir. 295, W.D., 1921, amended):

	Combat Reg.	General Service Reg.
Pumping sets, gasoline driven, centrifugal, 2-in. suction and discharge hose and connections	1	6
Pumps, hand-force with 2-in. suction and discharge	5	6
Bags, water, sterilizing	12	..
Basins, canvas, storage, 20 x 20 ft.	3	12
Hose, discharge, 2-in. 50-ft. lengths	10	19
Hose, suction, 2-in. 25-ft. lengths	7	13
Rope, ½-in. diameter, 200-ft. lengths	2	..
Shower baths, portable, 8-head, oil burner	..	1

Each company of the Water-Supply Battalion is equipped with 50 water-tank trucks, each truck having two tanks of 250 gal. capacity each, giving a total carrying capacity for the company of 25 000 gal. and for the Battalion of 75 000 gal. Each company is equipped with gasoline and repair trucks so as to form two complete units of 25 tank-trucks each. This unit, with two purification trucks giving a supply of 12 500 gal. and a potential output in addition of 7 000 to 12 000 gal. per hour, would be a normal assignment to a division. The 12 mobile purification trucks each contain apparatus necessary for chlorination and filtration at the rate of 3 500 to 4 800 gal. per hour or for chlorination only at the rate of 6 000 gal. per hour. The Battalion is also supplied with canvas water basins, water troughs, pumps and other miscellaneous equipment.

While certain items of equipment to be carried in the army dump can be standardized on the basis of average needs, no attempt should be made to list this equipment in detail until conditions in the theatre of operations are known.

II. Water Supply in Mobile and Stabilized Warfare.

Water supply on the march and in combat presents the most important and difficult problem facing the water-supply organization. Little time is available for other than the rapid development of existing wells or springs, the use of undamaged civil supplies, the use of streams or rivers by means of the purification truck, or the transportation of supplies from the rear. Conditions may exist where troop movements will be delayed until sufficient water for their needs is produced. It was a British saying in France that a division advanced astride a 4-in. pipe, and General Allenby's campaign in Palestine was made possible only by a 143-mile pipe line. The French Champagne offensive of 1915 was seriously checked in a limestone area where no water supply was available except from deep wells and existing wells had been filled by the Germans.

Reconnaissance. Reconnaissance for water should be included in all engineer reconnaissance and will be a special duty of water-supply troops. Notes should be taken of the location of all resources in the area, noting seasonal variation of supply and areas of possible artesian flow. Localities where shallow wells are likely to be successful should be noted.

Reconnaissance Reports on water supply should include the following:

Location (including map coördinates).
Source (well, spring, stream, etc.).
Character of Water (turbidity, taste, odor).
Result of Chemical and Bacterial Examination or Sample of Water.
Possible Sources of Pollution.
Rate of Flow.
Existing Development:
Data on: engines; pumps; electrical equipment; type and capacity of storage; kind, size, length and head of pipe line; present condition of equipment.
Well or Spring:
Depth; depth to water surface; material and extent of lining, curb and cover; diameter; method of raising water; temperature.
Stream:
Width; mean and maximum depth; nature of bed; height of banks; dams.
Proposed Development:
Nature; material available and required.

The following suggestions may be useful:

Streams in open country are usually bordered by trees.

Spots where the grass is greener in one place than another or the vegetation more abundant are more likely to be near ground water.

Vapor often rises in the early morning or evening from places where springs or ground waters may be found.

Springs are often found at the junction of valleys or at the base of an overhanging cliff.

Areas suitable for shallow wells will usually be found in valleys.

Maps showing existing water points and probable locations of water points in advance areas should be issued to all troops concerned. (Pumping stations, distribution lines and storage reservoirs should not be shown on maps going to front line troops.) A scale of 1 : 20 000 is desirable although 1 : 50 000 or 1 : 62 500 (the scale of the topographic map of the United States) can be nearly as useful. The following conventional signs are used:

Valves.....

Air valves.....

Check valves.....

Tees (with size).....

Laboratory.....

Mobile purification truck.....

Pump.....

Tanks and reservoirs (with number and capacity)

Water point.....

Water point, animals only.....

Horse troughs (show feet length).....

Railway water point.....

Railway spill tank.....

Well.....

Spring.....

Direction of dip.....

Flowing well areas.....

Pipe line or aqueduct (diameter may be shown)

Water works.....

Water tank train.....

On the March. The company water cart will be the means of distribution to troops on the march. It has a capacity of 110 gal. or sufficient water for about one day for an infantry rifle company. At bivouacs, sterilizing or "Lyster" bags may be set up and water carts refilled either from local sources or from tank trucks.

In friendly territory there will be opportunity for reconnaissance in advance. Temporary water points may be established near selected camp sites and reliance placed on the mobile purification truck. If local sources

are insufficient, water may be hauled from filling points by the tank-truck train. In enemy territory, the tank train should never precede the column although reconnaissance by the water-supply officer will usually be possible. Reliance will generally be placed on water points already existing or such as may be established in rear of the column. Small commands may have to locate and purify their own supply. Methods of sterilization should be applied to all waters from local sources.

During the Offensive. Preparation should be máde for troop concentrations in rear of existing lines and for maintaining the supply to troops as they advance. As the element of surprise becomes more important, time will rarely be available for deliberate preparations and many activities will be prohibited on account of enemy observation from the air. It should be the aim during quiet periods to develop supplies uniformly and extensively on all parts of the front where a concentration may be expected.

All troops should start a forward movement with canteens and water carts filled. As soon as the movement is arrested, tank trucks should bring forward additional supplies to designated water points. In rough country, pack mules carrying 5-gal. cans may be used. If tank trucks are not available they may be improvised by mounting iron tanks on trucks, the tanks being provided with internal baffle plates and securely fastened to the trucks. In some cases trucks may be loaded with wine casks or gasoline tins of water. If surface supplies are available, the mobile purification units should move forward. Work of more permanent character may then be started in order to release the purification units for a further forward movement. Available wells and springs should be cleaned out and used, and signs should be posted. Tube wells may be of great value or timber framing and corrugated iron for linings in case water can be obtained from dug wells.

Emergency equipment for cleaning wells and springs and installing temporary water points can be carried on a 1½- or 2-ton truck—or a 4-mule wagon, if roads are poor, is mobile and may be of great value on the march or during combat. It should usually include a windlass with buckets, shovels, pick mattocks, crowbar, blocks and rope, hand-force pumps, carpenters' and plumbers' tools, canvas water troughs and basins, Lyster bags, hypochlorite of lime in 1-g. capsules and in 1-kg. bottles or cans. The personnel should include an experienced noncommissioned officer, a carpenter, plumber and laborers.

At ½ gal. per man and 5 gal. per animal, an Infantry Division of 19 993 men and 6 929 animals requires about 45 000 gal. per day (31 gal. per min.). This is a minimum figure. Under average field conditions, 1 gal. per man per day and 10 gal. per animal per day should be allowed — a total of 90 000 gal. With each tank truck making one round-trip a day, 180 trucks will be employed, and the most careful organization will be necessary to maintain this service. Under some conditions, water may be advanta-

geously hauled in special light railway tank cars of 2 000 gal. capacity. If tank cars are not available they may be improvised from flat cars by fitting them with iron tanks of suitable size. A standpipe should be erected for filling the railway tank cars, and spill tanks should be provided at the railhead to receive the supply brought up by the train. Arrangements must be made here for filling the tank trucks. If the spill tanks can be located at the top of an embankment, the water can be delivered to the trucks without pumping. If this is impossible, the water must be pumped to overhead tanks or directly to the trucks.

Local Sources in Stabilized Areas. The extent to which wells can be dug, reclaimed or driven, or small purification plants installed in the division area depends on the sources available and the intensity of shell fire. Such water points should be developed for filling water carts or buckets and canteens as required, and they should be provided with adequate chlorinating apparatus. If a safe water cannot be provided at these sources, it is better to carry it from the rear. Water taken from shell holes is a fruitful source of sickness, particularly after gas shelling. Water tainted by gas cannot be purified by boiling.

Springs form excellent water points. They should be protected against contamination and provided with chlorinating tanks, hand pumps, and faucets for drawing off the water. Fouling will occur if men are allowed to dip any sort of receptacles into the spring.

Small filters may often be used which are compact enough to be erected in forward dugouts or shelters. During long periods of position warfare it will sometimes be possible to dig or drive wells in a dugout in the trench system. Special precautions must be taken to protect them from drainage, and chlorinating arrangements must be provided.

Supply by Transport from the Rear. The water cart is the principal means whereby organizations transport water from water points. The carts may deliver to improvised tanks or Lyster bags. These points should be as far forward as they can be maintained and be reasonably secure from shell fire. They may be located at a mobile purification unit, or at a storage tank filled by tank trucks or light railway tank cars, or at springs or wells. Storage in front lines will often be handled by using gasoline (called by the British petrol) tins, holding 2 or 5 gal., which can be conveniently carried on pack animals.

Water may sometimes be delivered by light railway tank cars to railway spill tanks or in some cases direct to units along the track. This can often be arranged for artillery, the light railway delivering ammunition and water at the same time.

Pipe line distribution to water points will not often be used when other forms are available. In any area under shell fire breaks will be common, with interruption of supply and waste of water, and it will rarely be possible

to maintain the system within 4 000 or 5 000 yds. of the front lines. They involve a large amount of skilled labor for construction and maintenance and, where boundaries are constantly changing, difficulties are introduced by the necessity of supplying different units from the same system. If pipes are installed, the plan should be simple, and no branches taken from the main line other than short ones to storage tanks. Flow should be by gravity, if possible, and the line should be buried from 1 to 3 ft. for protection against frost and shrapnel. Water points will usually consist of small tanks filled directly from the main and of sufficient capacity to provide for supply during periods when the main is out of commission. They should be provided with faucets for filling canteens and buckets.

Supply in Corps and Army Area. Methods of distribution are similar to those in the division area, but on a larger or more permanent scale, with a view to releasing the mobile equipment for areas farther forward. Pipe lines are not used where local sources can be sufficiently developed.

A Field Army is assigned 15 evacuation hospitals of 750 beds each; 12 surgical hospitals of 250 beds each; and one convalescent hospital of 5 000 beds. If possible, all hospitals should receive piped supplies available at kitchens, operating rooms, and baths. Veterinary evacuation hospitals and veterinary general hospitals are army units requiring relatively large amounts of water, which should be piped if the permanence of the location will permit.

Communication Zone. Requirements in the communication zone are usually of a semi-permanent character consisting of piped supplies to concentration camps; general hospitals (to be provided for 15 per cent. of the combat troops); station hospitals for communication zone troops; schools; regulating stations; and supply depots. In camps, water is piped to kitchens, bath houses and latrines. Development usually is in the hands of officers whose civil training has given them the experience necessary to design large collecting, distributing, and sterilizing systems. In many cases, it is sufficient to enlarge the supply already developed by a city or town, or to install means for purifying such supplies.

III. Sources of Supply.

Rainfall and Streamflow. Other things being equal, the amount of rainfall on the area determines the volume of ground water and run-off. The intensity of precipitation influences its division into ground and surface flow. Streamflow during dry and frozen seasons is maintained largely from ground water sources, and the failure of streams in dry seasons indicates a lowering of the water table below the stream bed.

The amount of rainfall varies from nothing in the deserts of Africa, Asia, and parts of America to over 300 in. a year in parts of India. In the

United States, east of the Appalachian Mountains, the range is from 40 to 50 in. with a run-off of 20 to 30 in. Between the Appalachians and the Mississippi the average is about 30 in. with a run-off of 10 in. Between the Mississippi and the Sierra and Cascade ranges, except on the Rocky Mountains, the rainfall is less than 20 in. and the run-off is about three inches. Between the Sierras and the Pacific Coast (excepting certain arid areas in California), both rainfall and run-off are high and may exceed 100 in.

The number and size of tributaries to the larger rivers vary with the permeability of the surface and the rainfall and topography of the area. Where rainfall is evenly distributed, as in temperate countries, streams normally flow throughout the year, with high water during winter or spring. In the Southwestern United States, flood flows may occur at any time of intense rainfall, the stream dwindling to almost nothing in periods of dry weather. In areas of igneous or granite rock small streams are usually numerous and the water clear. In a clay country, large amounts of sediment are carried after heavy rains, and the streams may dry up in dry weather. Limestone areas are usually so pervious that surface water disappears quickly and small streams are scarce. Areas of sand and gravel are also pervious and, while at times this fact may decrease the number of brooks and streams, the ground water is often held near enough to the surface to replenish the streams during periods of low rainfall or when precipitation is held on the surface in the form of snow. Such water is usually clear and of excellent quality.

In the waters of lakes and ponds, sunlight, aëration and the settling of sediment have a considerable influence on the destruction of bacteria. In small ponds there is less dilution of the impurities washed into them. Decaying leaves may accumulate and with the growth of water organisms give the water a dark color and noticeable taste. Such color does not make the water dangerous any more than the green slime which may collect on the surface, but both are objectionable and may mask dangerous conditions. Bubbles of gas which rise to the surface when the bottom is disturbed are due to accumulations of decayed vegetable matter and silt. Some small ponds, fed from unpolluted springs, are excellent sources of supply. Ponds used by animals should not be used for camp supplies.

The value of storage may be materially modified by evaporation, even in temperate countries. In arid countries, like Egypt and the Sudan, the evaporation from water surfaces is reported to be 5 ft. per year and in Central Australia over 8 ft.

Sources of Underground Water. Most rocks contain water either in cavities or in the pores. The water is given up from the pores only by coarser rocks such as sandstones. If water is obtained from the fine-grained rocks, it is usually from joint or fault planes.

In sands and gravels, it is not unusual to find 30 per cent. of the volume made up of free space between the grains. In such deposits the mass below

ground water level yields abundant supplies. Because of the readiness with which such deposits yield their water, wells sunk close together may affect one another. The readiness of movement also causes fluctuations of the water level which may rise and fall rapidly with the beginning and cessation of rain. To obtain permanent supplies wells should draw from an elevation below the ground water level in the driest years. Surface waters passing through sand are subjected to a natural filtration. In the coarser sands and gravels conditions are less favorable, but, if taken from a considerable depth, the water is usually safe.

Clay usually contains large quantities of water, but its pore spaces are so small that little or none of the water can be utilized. Clay is of importance as a confining layer which prevents water from escaping or as a layer holding water in overlying porous beds.

Till (glacial deposits of clay, sand, gravel and bowlders) varies from porous to impervious according to the proportion of clay. It furnishes a large part of the water in rural districts in Northern United States, but, because of the occurrence of water in definite channels, the success of wells varies. Dug wells are more suitable than other types, having larger contact areas and larger storage capacity. The water is usually uncontaminated owing to its slow penetration through the clay and sand. In some places springs have formed channels, and, if such a channel leads from a source of pollution, the water may be dangerous.

Sandstone (a sedimentary rock) is the best water bearer of the solid rocks. Under favorable conditions it is saturated below the ground-water level and yields water freely. Conglomerates are less frequently encountered, and their absorptive power is not so great, but they may furnish considerable water. Because the pores in quartzite have been filled with silica it is not an important source of supply. Sandstone waters are rarely polluted, owing to the filtration in the porous varieties and the difficulty with which contaminated waters penetrate the more compact rocks. In quartzite, however, the joint fractures may admit polluting materials from the surface.

Slate (a metamorphic rock) is a poor carrier but may yield water from bedding, joint and cleavage planes. It is most important as a confining layer to prevent the escape of water from sandstones which may be interbedded with it.

Limestone (a sedimentary rock) usually carries water in open channels or caverns dissolved by water which originally followed joint or bedding planes and gradually enlarged them. The occurrence of caverns or passages can seldom be predicted but most deep wells encounter such passages. The waters are generally hard but not otherwise mineralized. In the vicinity of settlements these waters are frequently contaminated, as the rain water often moves directly into underground channels instead of filtering through the soil.

Granites (of igneous) and gneisses (of metamorphic origin) are dense

and usually have little pore space for water. The largest supplies in these rocks are obtained from the joints which are most common near the surface. Water supplies, if obtained, are usually within 200 or 300 ft. The joints occur in complex systems of intersecting planes, and it is possible for pollution to reach wells at depths of several hundred feet.

Location of Ground Waters. The ground water has a definite upper surface called the water table, which conforms in general with the broader surface irregularities but is flatter, often being far below the surface on hills and cutting it in the valleys. The movement of ground water is in the direction of the slope of the water table and approximates that of the surface drainage.

Flowing water from distant sources passing through a land of low rainfall, as the Nile or the Euphrates, will give a water table falling away from the river, the river supplying the subsoil water. In large river valleys the water table will often rise with a sustained rise of the river. Such water, absorbed during high stages and given up slowly during the dry season, is an important factor in maintaining river and lake levels. Near the ocean the elevation of the water table can easily be estimated as it rarely lies below sea level.

The occurrence of deep waters depends on the structure and character of rocks far below the surface, and the well may usually be located without reference to surface relief, except that, where artesian flows are expected, it should be on low ground. Information as to the best location may be obtained from a record of wells in adjacent areas or from a study of the rocks and their structure.

It is a wide-spread belief that water increases with depth and may be had anywhere by going deep enough. This is far from the truth. Rainfall is the source of over 99 per cent. of fresh ground-water and (neglecting the surface material above the water table) it decreases with the depth. The deeper rocks are largely granitic and hold little water. Unless they also constitute the surface rock and are broken by joints, it will be of little use to penetrate them. Unless there is some evidence that deep water-bearing beds exist, a deep well should be considered as an experiment, although in sedimentary rocks it may penetrate a number of water strata which furnish in the aggregate an adequate supply.

In connection with underground water supplies in dry areas, or where deep wells are required, the location of water bearing strata is almost an exact science to the geologist. Much wasted time and labor can be avoided by utilizing his knowledge. This was especially emphasized at Gallipoli where three small isolated beach areas, enfiladed by enemy artillery fire, were forced to rely on tank ships from Egypt which could land supplies only at night and in a calm sea.

FIG. 1. — TYPICAL FLOOD PLAIN WELL.

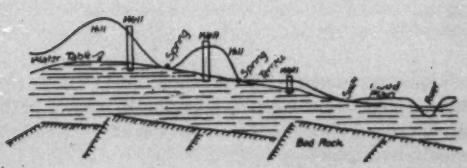

FIG. 2. — TYPICAL WATER TABLE.

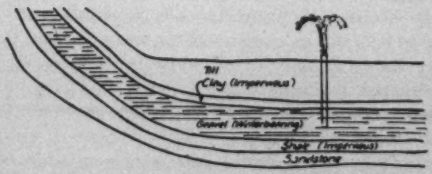

FIG. 3. — TYPICAL FLOWING* (ARTESIAN) WELL.

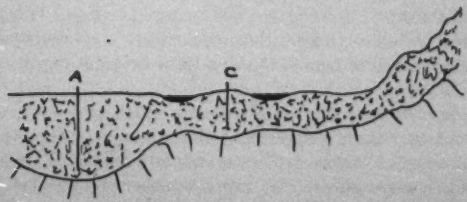

FIG. 4. — RIVER COURSE EXPLORED BY TUBE WELLS.

At C, only silt, no water obtained. Best results at A far from modern river course and now covered by agricultural land.

*An artesian well may be non-flowing, the water rising in the well to a height depending on the pressure head in the water bearing strata.

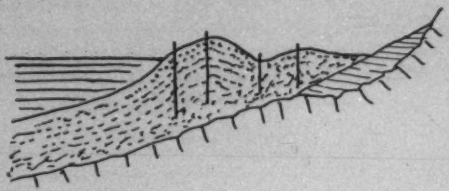

FIG. 5. — FRESH WATER IN BEACH AND DUNE DEPOSITS.

Water table rises toward land and is held up by heavier sea water without mingling except along a belt of diffusion.

Springs. Springs, under favorable conditions, are an ideal source of supply. When coming from considerable depths in the rock or through sand and gravel, they are usually free from pollution. The minerals contained are usually harmless.

A gravity spring flows from loose materials or open passages where an outcrop of impervious material forces the ground water to the surface. They are often formed by a ledge underlying saturated soil or by beds of sedimentary rocks of different porosity. They often flow from passages in glacial deposits or from solution channels in soluble rock. In limestone the passages may be miles in length. If the water is clear, they are usually of good quality, but, if found to be muddy after storms, they are liable to pollution from surface drainage.

An artesian spring is one where the waters are confined between impervious layers under hydro-static pressure. Such a spring often flows through faults or fissures and carries considerable amounts of water.

In a seepage spring the water seeps from sand or gravel deposits. It may emerge above an underlying impervious bed but usually occurs where valleys cut into water-bearing deposits. Such springs are likely to be found in small swales cut back into a slope, the flow of water being the cause of the swale and the swale tending to concentrate the flow. They are usually marked by vegetation at their outlets and are often colored from vegetable matter or the presence of iron. Coming from no great depth, they are not often very cold.

Springs may be expected along streams which have carved deep beds. Should the stream water appear and disappear at intervals, it may be difficult to differentiate between the stream and a spring. The temperature of the water is a good guide. In warm weather the surface flow will be warmer, and in cold weather the reverse will be the case.

Some limestone springs are intermittent in action, such as that at the Pool of Siloam at Jerusalem, referred to in the Bible as the "Disappearing Waters." The reason here is that a natural siphon in the rock expels the contents of a cavity when the water reaches a certain level. Some hours are then necessary before the water will again reach a level permitting flow.

Selection of Type of Well. The specific capacity of a well is the yield in g.p.m. divided by the number of feet the water surface is drawn down. A specific capacity of 100 is high, 20 is moderate and 5 is low. Values of 100 or higher can be obtained only in thick beds of coarse sand or gravel. The yield of a well is determined by the character of the water-bearing material. A sand will furnish large supplies, while a chalk or clay — although possibly containing more water — will yield little or none. Quicksands contain large amounts of water, but, owing to the ready flow of the fine sand, dug wells are impossible and driven wells with ordinary strainers become clogged. Solution passages or joints in rock play an important part in determining yield and may afford excellent supplies where the mass of the rock contains no water.

In loose materials, water accumulates most easily in stone curbed, uncemented, dug wells, somewhat less in tightly curbed dug wells with open bottoms. If the materials are so consolidated as to prevent them entering the well, water will enter an iron casing open at the bottom. In soft materials, perforated casings or screens are necessary. In the harder rocks, casings are unnecessary except to prevent entrance from undesirable levels.

The amount of storage in a well is important when the rate of flow is low. The storage capacity varies as the square of the diameter, and a 3-ft. well will hold 36 times as much water as a 6-in. well. Dug wells are of advantage in any material where water enters more slowly than it can be lifted by the pumps. Bore holes should be made as large and as deep as possible below the entrance point of water if the flow is inadequate.

It is a common belief that wells in lowlands near a river receive their water from the river. Under normal conditions, as shown in Fig. 1, this is not the case, the well being supplied by the ground water. Should the amount of water pumped from the well be greater than can be supplied by the ground water, the water table will be lowered, as shown by the dotted line, and the supply may be drawn from both the ground water and the river. The arrows indicate the normal ground water movement.

The time available will often be important in determining the type. Drilled wells require considerable time and equipment for installation and can be used only under favorable conditions in stabilized areas. Dug and driven wells will usually be the type used in forward areas, and one of the outstanding features of the War was the extent to which tube wells were used to render large supplies of water available at a few hours notice.

The limitations of drilled wells should be realized as in France there was some disappointment at the small yield. Holes striking a fissured system in chalk, limestone or marl (or when coarse sands, gravel beds or sandstone occur below the water table) may give a large yield. The services of the geologist are here of the utmost importance as, in many cases, the deviation of 100 yds. from the point selected would have meant failure. In any event, it will be foolish to expect water in wells which do not exceed the depth of nearby ravines.

Sites for Tube Wells. River valleys, whether ancient or modern, if wide and with little slope, often have large silt deposits. Such deposits are valueless and should not be tried, unless sandy surface deposits can be located. Valleys of medium width and more slope will usually have current enough to carry away the finely suspended matter and have underlying beds of sand and gravel through which water will flow independent of that on the surface.

Deltas of large rivers usually have sand deposits, although the water supply may be limited by the presence of clay. Ancient beds of sand and gravel are at times covered by layers of clay which must be pierced, as in Egypt. A failure in one place need not prevent further trials. In Egypt, where the surface water was condemned even for washing, pure water could be obtained from a layer of sand about 150 ft. below the general level of the delta, the water rising to approximately the level of the surface water.

Plains with meandering rivers and lakes are likely to be composed of clay or sandy clay, which will not yield sufficient amounts to tube wells, although large shafts may fill by percolation. The surrounding hills will often furnish a clue to the direction in which ravines or valleys discharge their subsoil drainage. Plains with a slight gradient may have the water table close to the surface. Natural artesian flows have been obtained from sands less than 30 ft. below a cover of loam.

In beach and dune areas, the sands below sea level may be saturated with fresh water. Tubes within a few yards of high water often give excellent supplies unless drawn too heavily. If a well near the sea is pumped faster than the sands or gravels can transmit water, salt water may be drawn in. Such wells of fresh water often ebb and flow with the tide, showing the influence of the sea on the water table. During the Gallipoli Campaign limited quantities were obtained from the beach sands at Anzac with a very narrow margin between the hills and the sea. At Helles, supplies were obtained where ravines cut into the cliffs along the shore. Along the Sinai and Palestine coasts, tubes were successfully used in the dune areas. Well parties in the Sinai Desert found the best water near the coast and where there was least vegetation. No drinkable water was found near palm groves and, where there was much shrub on the dunes, saline water could be expected. In Macedonia a division was supplied from tube wells, some within 300 ft. of the sea, within six hours of landing. Near the pyramids of Gizeh, 30 000 men were supplied from a 6-in. tube well, 120 ft. deep.

IV. Hydraulics.

Symbols Used.

v = velocity in ft. per sec.
p = pressure in pounds per sq. ft.
w = weight of 1 cu. ft. of water = 62.4 lbs.
g = acceleration due to gravity = 32.2 ft. per sec. per sec.
z = potential head = height above any assumed datum plane.

h = total head in feet.
h_1 = friction head (head lost on account of friction)
l = length of pipe line in feet.
d = diameter of pipe in feet.
f = friction factor.
Q = discharge in cu. ft. per sec.
a = area in sq. ft.

$$r = \text{hydraulic radius} = \frac{\text{area of wet cross section}}{\text{wetted perimeter}}$$

$$= (\text{for pipes flowing full}) \frac{d}{4}$$

$$s = \frac{\text{head in feet}}{\text{length in feet}} = \frac{h}{l}$$

= sine of angle of slope

$$(\text{for long pipes } s = \frac{h_1}{l} \text{ approximately})$$

C = a coefficient.

$\frac{v^2}{2g}$ = head required to produce a given velocity

Flow in Pipes. In steady flow with friction

$$h = \frac{v^2}{2g} + h_1 \quad (1)$$

or, the total head on the outlet equals the head required to produce the velocity at the point of discharge plus the friction head. If, as explained below, the lost head h_1 be expressed in terms of v, equation (1) becomes the general equation for the solution of problems concerning pipe flow, other losses than those due to pipe friction being neglected.

Lost Head. In a straight pipe of uniform section the only losses of head of importance are the head lost at entrance and that lost in pipe friction. Sudden changes in direction or diameter or obstruction to the flow by partially close valves introduce losses which need not be considered here.

$$\text{Head lost by friction} = f \frac{l}{d} \frac{v^2}{2g} = h_1$$

The friction factor, f, decreases as the velocity increases and as the diameter increases; it increases with the roughness of the pipe. The friction head, h_1, is directly proportional to the length of pipe; is inversely proportional to the diameter; increases nearly as the square of the velocity; increases with the roughness, and is independent of the pressure. Rewriting equation (1), we have at the pipe outlet:

$$h = \frac{v^2}{2g} + f \frac{l}{d} \frac{v^2}{2g} \quad (2)$$

$$= \frac{v^2}{2g} \left(1 + f \frac{l}{d} \right)$$

Assuming a 12-in. pipe line, 4 000 ft. long with the reservoir surface 100 ft. above the discharge, 98 per cent. of the head is lost in friction. If the pipe is long (over 1 000 times the diameter) the loss by friction is so nearly the entire head that (2) may be written:

$$h = h_1 = f \frac{l}{d} \frac{v^2}{2g} \quad (3)$$

$$\text{and } v = \sqrt{\frac{2ghd}{fl}} = 8.02 \sqrt{\frac{hd}{fl}}$$

Solution of Pipe Problems. In the Chezy formula

$$v = C \sqrt{rs} \quad \text{and} \quad Q = av \quad (4)$$

In this formula, C can be obtained from Table 1. A mean value of C for new pipes is approximately 115.

A common problem in pipe flow is: having h, l, and d given, find v and Q. For example, assume that $h = 100$ ft., $d = 12$ in. and $l = 4\,000$ ft., and, as a trial, assuming a value of $C = 115$ we have in equation (4)

$$v = 115 \sqrt{r\,s}$$

$$\text{here } \sqrt{r} = \sqrt{\tfrac{1}{4}} = 0.5$$

$$\sqrt{s} = \sqrt{\frac{100}{4\,000}} = \sqrt{.025} = .158$$

$$v = 115 \times 0.5 \times .158$$

$$= 9.1 \text{ ft. per sec.}$$

Taking 9 ft. per sec. as sufficiently close, we find the value of C from Table 1 to be about 115, so no recomputation is necessary. If it should be found that the velocity computed does not correspond with a value of C in the table substantially equal to that assumed, a value of C corresponding to the velocity in the trial computation may be taken from the table and the formula recomputed for a new value of v.

$$\text{Finally: } Q = av = .785 \times 9 \quad (a = .785d^2)$$
$$= 7.06 \text{ cu. ft. per sec.}$$

The usual method of finding the diameter necessary to deliver a certain amount of water, having h, l, and Q given, requires finding the fifth root. It is generally easier to assume a diameter and solve equation (4) for v and Q. An estimate can then be made of the necessary amount to increase or reduce the trial diameter so that the equation will give the required value of Q. Here it may be useful to note that the discharge varies about as $d^{2.5}$. Since the velocity increases with the diameter, a direct relationship does not exist.

Example: To compute the diameter necessary to discharge 9 second ft. with a head of 50 ft. in a distance of 2 miles. For a trial, assume d = 10 in. and C = 108.

$$\text{Then } v = 108\sqrt{r\,s}$$
$$= 108 \times .456 \times .0688$$
$$= 3.45 \text{ ft. per sec.}$$
$$\text{and } Q = av = 0.545 \times 3.45 = 1.88 \text{ second ft.}$$

The value required, 9 second ft., is about five times the result obtained. Inasmuch as the velocity is somewhat larger with a larger pipe, make a second trial with a pipe having an area about four times that of a 10-in. pipe or one having a diameter the square of which would be about 4×10^2, namely a 20-in. pipe. With a 20-in pipe

$$\text{take } C = 113$$
$$\text{and } v = 113\sqrt{r\,s}$$
$$= 113 \times .646 \times .0688$$
$$= 5.0 \text{ ft. per sec.}$$
$$Q = 2.18 \times 5.0$$
$$= 10.9 \text{ sec. ft.}$$

This is satisfactory. The next smaller size, 18 in., must give a discharge less than $\frac{18^2}{20^2} \times 10.9 = 8.8$ and this will be too small.

TABLE 1.

VALUES OF C FOR IRON PIPES.

(By Williams, American Civil Engineers Pocket Book, p. 1089)

Diameter in inches.	VELOCITIES IN FT. PER SEC.							
	FOR NEW PIPE.				FOR OLD PIPE.			
	1	3	6	10	1	3	6	10
3	95	98	100	102	63	68	71	73
6	96	101	104	106	69	74	77	79
9	98	105	109	112	73	78	80	84
12	100	108	112	117	77	82	85	88
15	102	110	117	122	81	86	89	91
18	105	112	119	125	86	91	94	97
24	111	120	126	131	92	98	101	104

At times it will be necessary to determine the size required and then compute the number of pipes of a smaller size which discharge the required amount. Based on the fact that relative discharge varies as the $\frac{5}{2}$ power of the diameter, Table 2 supplies means of determining this for the sizes commonly used. Example: To find size of pipe necessary to supply 28 branches of 1-in. pipe. Read down column headed "1 in." until the next larger number is found, in this case 29, and find answer in Col. 1 at the left which gives diameter of pipe required as 4 in.

TABLE 2.

RELATIVE CAPACITY OF PIPES OF DIFFERENT DIAMETERS.

Diameter	1-in.	2-in.	4-in.	6-in.	8-in.	10-in.	12-in.	15-in.
1-in.	1.	.18	.034	.012	.0062	.0035	.0022	.0012
2-in.	5.5	1.0	.19	.067	.034	.019	.012	.0068
4-in.	29.0	5.3	1.0	.36	.18	.10	.067	.036
6-in.	80.0	15.0	2.8	1.0	.77	.29	.018	.10
8-in.	160.	29.0	5.5	2.0	1.0	.56	.36	.20
10-in.	282.	52.0	10.0	3.5	1.8	1.0	.62	.34
12-in.	443.	81.0	15.0	5.5	2.8	1.6	1.0	.56
15-in.	806.	148.	28.0	10.0	5.0	2.9	1.8	1.0

The hydraulic gradient is a line through points above the pipe line at distances equal to the pressure head in the sections below. Practically, for a pipe of uniform size discharging freely, it is a line drawn from the reservoir surface to the outlet of the pipe and for a long pipe the slope of the gradient is approximately $\frac{h}{l}$. The vertical distance of this line below the level of the water surface in the reservoir will, for practical purposes, equal at any point $h_1+\frac{v^2}{2g}$ and the gradient may be plotted by laying off these distances, a few points usually being sufficient. If the velocity head is constant, the drop in the hydraulic gradient is a measure of the loss of head between any two points in the pipe line.

If a pipe is laid so that a portion of it rises more than a few feet above the gradient, interference with the flow will probably occur through gathering of air at the summit, unless a pump is placed for exhausting the air. Such summits will sometimes occur where the pipe line runs over flat ground and then down a steep slope. If not possible to place the reservoir nearer the crest of the slope, the trouble can at times be obviated by using a larger pipe on the flat slope and so reducing the friction head in that section and changing the form of the hydraulic gradient.

The greater number of military pipe problems may be solved with sufficient accuracy by Table 3 for long pipes. It applies to new straight cast- or wrought-iron pipes, and may be used to advantage for problems involving the sizes given and applies equally to steel or wood. The discharge coefficient for riveted steel is 10 per cent. to 25 per cent. less than for smooth new iron.

Example: Being given a 6-in. pipe, 3 000 ft. long with a total head of 36 ft., find the velocity and the discharge: The friction head per 100 ft. will be $100\times\frac{36}{3\,000}=1.2$. From the table for 6-in. pipe the velocity is found to be 4.0 ft. per sec. and the discharge 352 g.p.m. For old pipe, enter the table with only one-half the available head. If the above problem were for old pipe, the fricton head used would be 0.60 per 100 ft., the velocity would be 2.8 ft. per sec. and the discharge 247 g.p.m. Similarly if the velocity is given, the actual friction head for an old pipe may be obtained by multiplying the tabular value by 2. For a velocity of 4.0 ft. per sec., the friction head in an old 6-in. pipe is 2.4 ft. per 100 ft. The discharge must be reduced to allow for the age of any pipe which has been, or is expected to be, in service more than one or two years. The term "old pipe" as used here applies to an age of 10 years or more.

Find the diameter of a pipe to discharge 4 g.p.m. under a head of 21 ft. in a pipe line 1 000 ft. long. Here the friction head is 2.1 ft. per 100 ft. The table shows a discharge of 4.4 g.p.m. under 1-in. pipe with a velocity of 1.3 ft. per sec. and the 1-in. pipe could be used. In connection with branching pipes it is usually necessary to compute each branch separately, but note may be made of the fact that the friction head in a pipe discharging uniformly throughout its length is about one-third that of a pipe discharging only at its end.

If a check computation is desired on the application of the Chezy formula $v=\sqrt{rs}$ or on data taken from Table 3, equation (2) can be used with a value of f based on the following equations of Darcy:

$$\text{new pipe}\quad f=0.02+\frac{0.02}{12d}$$

$$\text{old pipe}\quad f=0.04+\frac{0.04}{12d}$$

As f varies with the velocity, the values are not exact but they are sufficiently so for use here. (d = diameter in feet and 12d here = pipe diameter in inches.)

TABLE 3.

DISCHARGE AND FRICTION HEAD FOR CLEAN IRON PIPES.

(From Values of f by Merriman)

	1-IN. PIPE.			2-IN PIPE.		
Velocity ft. per sec.	Discharge, Sec. ft.	Discharge, Gals. per min.	Friction hd., ft. per 100 ft.	Discharge, Sec. ft.	Discharge, Gals. per min.	Friction hd., ft. per 100 ft.
1.0	.00545	2.44	0.7	.0218	9.79	0.33
1.2	.00655	2.95	1.0	.0262	11.8	.46
1.4	.00764	3.43	1.4	.0305	13.7	.60
1.6	.00878	3.94	1.7	.0348	15.6	.77
1.8	.00982	4.40	2.1	.0394	17.7	.93
2.0	.0109	4.89	2.5	.0437	19.6	1.1
2.2	.0120	5.38	3.0	.0480	21.5	1.3
2.4	.0131	5.86	3.5	.0524	23.5	1.6
2.6	.0142	6.36	4.0	.0567	25.4	1.8
2.8	.0153	6.85	4.5	.0612	27.5	2.0
3.0	.0164	7.34	5.2	.0655	29.4	2.3
3.2	.0175	7.86	5.9	.0698	31.3	2.6
3.4	.0185	8.30	6.5	.0742	33.3	2.9
3.6	.0197	8.83	7.1	.0785	35.2	3.2
3.8	.0207	9.28	7.9	.0828	37.2	3.6
4.0	.0218	9.80	8.7	.0874	39.2	4.0
4.2	.0228	10.2	9.3	.0917	41.1	4.3
4.4	.0240	10.8	10.2	.0960	43.1	4.7
4.6	.0252	11.3	11.1	.100	45.0	5.1
4.8	.0262	11.7	12.0	.105	47.1	5.6
5.0	.0274	12.3	13.0	.109	48.9	6.0
5.2	.0284	12.7	14.0	.114	51.2	6.4
5.4	.0295	13.2	15.0	.118	53.0	6.8
5.6	.0305	13.7	16.0	.122	54.8	7.3
5.8	.0317	14.2	17.0	.127	57.0	7.8
6.0	.0327	14.7	18.0	.131	58.8	8.4
6.2	.0339	15.2	19.0	.135	60.6	8.9
6.4	.0348	15.6	20.0	.140	62.8	9.5
6.6	.0360	16.2	22.0	.144	64.6	10.0
6.8	.0372	16.7	23.0	.148	66.5	10.5
7.0	.0382	17.1	24.0	.153	68.5	11.0
7.2	.0393	17.6	25.0	.157	70.4	11.6
7.4	.0404	18.1	27.0	.162	72.4	12.2
7.6	.0415	18.6	28.0	.166	74.4	12.9
7.8	.0425	19.1	29.0	.170	76.3	13.4
8.0	.0437	19.6	31.0	.175	78.6	14.2
8.2	.0447	20.1	32.0	.178	80.0	14.9
8.4	.0459	20.6	34.0	.183	82.2	15.5
8.6	.0469	21.0	35.0	.188	84.4	16.4
8.8	.0480	21.5	37.0	.192	86.2	16.7
9.0	.0492	22.1	38.0	.197	88.4	17.0
9.2	.0502	22.5	40.0	.200	89.8	18.0
9.4	.0514	23.0	41.0	.205	92.0	19.0
9.6	.0524	23.5	43.0	.210	94.2	20.0
9.8	.0536	24.0	45.0	.213	95.6	21.0

Velocity ft. per sec.	4-In. pipe. Discharge, Sec. ft.	4-In. pipe. Discharge, Gals. per min.	4-In. pipe. Friction hd., ft. per 100 ft.	6-In. pipe. Discharge, Sec. ft.	6-In. pipe. Discharge, Gals. per min.	6-In. pipe. Friction hd., ft. per 100 ft.
1.0	.0874	39.2	0.14	.197	88.4	.087
1.2	.105	47.1	.20	.235	105	.13
1.4	.122	54.8	.27	.275	123	.17
1.6	.140	62.8	.34	.314	141	.21
1.8	.157	70.5	.41	.354	159	.27
2.0	.175	78.6	.50	.394	177	.34
2.2	.192	86.2	.60	.432	194	.39
2.4	.210	94.2	.71	.472	212	.46
2.6	.227	102	.82	.510	229	.53
2.8	.245	110	.94	.550	247	.60
3.0	.262	118	1.07	.588	264	.70
3.2	.278	125	1.2	.628	282	.79
3.4	.295	132	1.3	.668	300	.88
3.6	.314	141	1.4	.707	317	.97
3.8	.332	149	1.6	.747	335	1.08
4.0	.348	156	1.8	.784	352	1.2
4.2	.367	165	1.9	.825	370	1.3
4.4	.384	172	2.1	.864	388	1.4
4.6	.402	180	2.3	.904	405	1.5
4.8	.418	188	2.5	.942	423	1.6
5.0	.437	196	2.7	.982	441	1.8
5.2	.453	203	2.9	1.02	458	1.9
5.4	.472	212	3.1	1.06	476	2.0
5.6	.488	219	3.4	1.10	494	2.2
5.8	.507	227	3.6	1.14	512	2.3
6.0	.524	235	3.9	1.18	530	2.4
6.2	.542	243	4.1	1.22	548	2.6
6.4	.558	250	4.4	1.26	566	2.8
6.6	.577	259	4.6	1.30	584	2.9
6.8	.594	266	4.9	1.34	601	3.1
7.0	.610	274	5.1	1.38	619	3.2
7.2	.628	282	5.4	1.41	634	3.4
7.4	.645	289	5.7	1.45	651	3.6
7.6	.663	298	6.0	1.49	669	3.8
7.8	.680	305	6.3	1.53	687	3.9
8.0	.698	313	6.6	1.57	705	4.1
8.2	.715	321	6.9	1.61	723	4.3
8.4	.734	329	7.2	1.65	740	4.5
8.6	.750	336	7.5	1.68	754	4.7
8.8	.769	345	7.8	1.73	777	4.9
9.0	.785	352	8.1	1.77	794	5.1
9.2	.804	361	8.5	1.80	808	5.3
9.4	.820	368	8.8	1.85	830	5.5
9.6	.838	376	9.1	1.88	844	5.7
9.8	.856	384	9.4	1.92	862	6.0

Pipe Line with Pump. A pump requires power not only to lift water through the height, h, but also to overcome the friction head h_1 in the suction and discharge piping, so that the pump works against a head $h+h_1$. The expression h_1 includes the velocity head of discharge. The power of a pump is:

$$\text{foot pounds per sec.} = \frac{w(h+h_1)}{e}$$

where w = number pounds lifted per second
e = efficiency

To raise 20 cu. ft. per sec. 16 ft. with a pump efficiency of 0.62 and a friction head of 4 ft.

$$\frac{20 \times 62.4 \times 20}{0.62} = 40\,260 \text{ ft. lbs. per sec.}$$

This divided by 550 gives 73.2 h.p.

If a complete vacuum could be produced below the plunger of a pump and if there were no friction, the suction lift would be equal to the atmospheric pressure (in feet of water) or about 34 ft. In practice the suction lift is limited to 24 ft. (preferably 20 ft. or less).

Measurement of Flow in Open Channels. The Chesy formula, previously mentioned, may be used but this entails more accurate measurement of elevations to determine the slope than can be made under ordinary service conditions. The velocity-area method may be used or the discharge may be measured over a dam or specially constructed weir.

The velocity-area method consists in dividing a cross-section of the river (as determined by soundings) into a number of sections according to the accuracy desired, and determining the mean velocity in each section. The discharge in any section will equal its area times the velocity, or $Q = av$. For accurate work a current meter should be used and measurements made at 0.2 and 0.8 of the depth in any vertical (or more roughly a single measurement at 0.6 of the depth) give the mean velocity in that vertical. In determining river discharge it is usual to plot a rating curve (discharge against gage height) so that discharge in cubic feet per second can be determined for any stage of the river. For approximate work surface floats may be used, taking the time required for the float to run a known distance. The length of run in feet, divided by the time in seconds, gives the velocity in feet per second of that part of the stream traversed by the float. A number of velocity determinations should be made at varying distances from the shore and the mean of the velocities (reduced by a coefficient) taken as the mean velocity of the cross section. The coefficient varies between 0.85 and 0.95. 0.9 is a mean value, and $Q = 0.9\ va$.

Weir Measurements. For accurate results the Basin formula which provides for velocity of approach should be used. There should be no end contractions (the weir should extend the entire width of the channel), and coefficients should be applied for any spillways with other than a sharp crest. The following table gives sufficient data for use in the field, where x = height of the crest above the bottom of the channel.

DISCHARGE OVER SHARP-EDGE WEIR (BAZIN FORMULA).

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH.

Hd. in ft.	x = 2	x = 5	x = 10
0.2	0.33	0.33	0.33
0.3	0.58	0.58	0.58
0.4	0.88	0.87	0.87
0.5	1.23	1.21	1.21
0.6	1.62	1.58	1.57
0.7	2.04	1.98	1.97
0.8	2.50	2.42	2.40
0.9	3.00	2.88	2.86
1.0	3.53	3.38	3.34
1.2	4.68	4.47	4.38
1.4	5.99	5.62	5.52
1.6	7.40	6.89	6.74
1.8	8.93	8.25	8.05
2.0	10.6	9.72	9.44
2.5	15.2	13.8	13.3
3.0	20.4	18.3	17.5
3.5	26.2	23.4	22.2
4.0	32.5	29.0	27.3
5.0	46.7	41.5	38.7

For many types of dams the flow is approximately the same as for a sharp-edge weir for heads up to 2 ft. For broad rectangular crests the discharge from the table should be multiplied by coefficients ranging from about 0.9 for a width of 1.5 ft. to 0.8 for widths of 3 ft. or greater. For ogee sections a coefficient of 1.1 may be used for heads of 1.5 ft. or over.

Discharge through sluice gates can be obtained with sufficient accuracy by the formula

$$Q = Ca\sqrt{2gh} = 8.02\ Ca\sqrt{h}$$

in which h = head on center of opening in feet (if the opening is submerged, h = difference in water level above and below the gate). A value of $C = 0.60$ will give results of sufficient accuracy for field use.

No computation discussed in this section requires a greater accuracy than that obtained by using three significant figures. Three-place log tables or a 10-in. slide-rule will be of use in the computations, particularly those which may involve powers and roots.

V. Development of Supply.

Estimates of Water Required. The water supply provided for civil consumption in most regions is rarely sufficient for military needs. During the World War, both French and English estimated minimum water requirements when troops were massed for an advance at about 150 000 gal. per day for every 20 sq. miles occupied. An Infantry Division of 20 000 men has about 7 000 animals. At one gal. per day, the men require 20 000 gal.; and at 10 gal. per day, the animals require 70 000 gal., a total of 90 000 gal. per day. The Cavalry Division requires 102 000 gal. with 7 500 men and 9 500 animals. The following table gives per capita consumption under average conditions:

	Gal. per capita per day	Remarks
Cities and Army Posts (peace)	100–200	Provides for water-borne sewage.
Cantonments, 30 000 to 50 000 troops	55	Men and animals. Includes water for kitchens, baths, steam heat, toilets, sewers and stables.
Semi-permanent camp in rest area	30	Includes piped supply for baths, toilets, etc.
Temporary camp	5	Men.
	10	Animals. For drinking, cooking, washing, disinfecting. No water borne sewage.
On the march and in bivouac	1	Men (¾ to 1½ gals.).
	10	Animals.
In battle, absolute minimum for not over three days	½–¾	Men.
	3	Animals (3 to 5 gal.).
Locomotives (standard gage)		7 000 gal. a day or 120 gal. per train mile with one locomotive.
Stationary engine (condensing)		2 gal. per h.p. hour.
Stationary engine (non-condensing)		4 gal. per h.p. hour.
Condensing water (wasted)		100 gal. per h.p. hour.
Gasoline engines (cooling water)		½–¾ gal. per h.p. hour.

These estimates must be modified according to circumstances, especially in hot climates. The requirements of the maximum month may exceed those of the average month by from 15 per cent. to 40 per cent.

Yield of an Area. For a rough estimate of the area necessary to furnish a supply it may be assumed that a run-off of about 1 000 000 gal. per day per square mile will be available in a temperate climate. The following may be used for estimates in areas similar to Northeastern United States with average temperatures between 45° and 55°Fahr.

Rainfall, inches	Evaporation, inches.	Run-off, inches.	Thousands of gallons daily per square mile.
30	20	10	500
36	21	15	750
42	22	20	1 000
48	23	25	1 200
54	24	30	1 500

The figures given above are for an average month and would not be available in dry periods unless adequate storage were provided. The attempt to use rainfall records to determine run-off should be discouraged as the relationship is complex and not thoroughly understood.

Yield from underground sources should be estimated by a geologist when possible. Under exceptionally favorable conditions, as in a large area of sandy soil, 900 000 gal. per sq. mile per day have been obtained (18.9 in. on the area with 44 in. rainfall). In other localities with the same rainfall, the yield might not be over 500 000 gal. per day per sq. mile or even as low as 100 000 gal.

If a well is pumped, the surface of the ground water adjacent to the well will be depressed, the water surface taking the form of a parabolic curve which joins the original water table at the circumference of the circle of influence. When the ground-water flow tributary to the area equals the amount of water pumped, a condition of equilibrium is obtained. Wells placed in the same stratum near together interfere according to the size and spacing of the wells, the radius of the circle of influence and the lowering of the ground water table. If a well has been pumped so as materially to reduce the water level, the yield may be measured by noting the rate of recovery when the pumping is stopped. If I = the rate of inflow in g.p.m., R = the rise of water level in hundredths of a foot, A = the quantity of water in gallons represented by a rise of 0.01 ft. and t = length of time interval in minutes, the rate of inflow for any interval may be expressed by

$$A = 7.48 \times \text{area in sq. ft.} \times 0.01$$

$$I = \frac{R\,A}{t}$$

The yield of a spring is best measured by taking the time required to fill a container of known size. Tests of yield, however, for either springs or wells are of value only in computing flow for existing conditions of ground-water level. Allowance should be made for any indications that the amounts of water available may be reduced, either by depletion of the supply or by a lowering of the ground water level in dry seasons.

Development of Streams. The methods of developing surface streams may vary from pumping by means of the mobile purification truck to constructing impounding reservoirs for the supply of a cantonment, concentration area or general hospital.

Dams will rarely be required during military operations, but may at times be useful for equalizing the flow of streams to cover variation in draft. Dams of any size or permanence will be in the hands of engineers experienced in such construction, but temporary timber structures may be useful in suitable locations. Small dams may be quickly improvised by placing sand bags filled with earth where a rocky or firm foundation is

available. If the base is prepared and the bags are carefully built up by cross-locking, a reasonably substantial structure can be improvised. If a spillway or by-pass for storm water is arranged, they may even withstand fairly heavy floods.

Development of Springs. A collecting basin should be constructed. Water-tight timber casing may be used but will be objectionable if permitted to become old enough to decay. Concrete is preferable. Water-tight walls should extend a foot or two above and below the surface to prevent the entrance of surface wash. The shape of the springy area should determine the shape of the reservoir. Small springs may be developed by setting a length of large concrete, iron or vitrified pipe in the ground vertically over the spring. A cover should always be provided to keep out dust, leaves, sticks and small animals. Every care should be taken to guard against pollution, particularly such as might occur from dipping buckets or dippers into the spring, and the water should be taken by a pipe to the point of delivery.

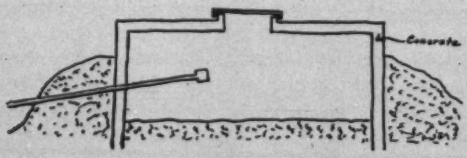

FIG. 6. — DEVELOPMENT OF SPRING.

Dug Wells. Dug wells require a considerable expenditure of time and labor. For depths over 20 ft., it usually is more economical to use some other method. Excavation is with pick and shovel, and there is usually room for only one man to work at the bottom. A windlass and bucket must be provided for lifting out the excavated material. The size of the shaft depends on the amount of storage required, the type of lining and the method of raising the water. Shafts using a windlass and bucket require a diameter of at least four feet. Where considerable storage is required, diameters of from 15 to 20 ft. may be called for. It is usually desirable to install the permanent pump during excavation for use in removing water.

Linings may be of brick, masonry, timber, concrete or corrugated iron, depending on the diameter of the well, the character of the soil and the time and material available. For field use, timber is the most useful, and shafts may be sunk as in mining operations. The top of the well should be secured from contamination by raising the lining above the ground level and covering the opening. The curbing should be water-tight for at least six feet below the ground surface. The direction of ground-water flow should be *from* the well *toward* any nearby source of contamination.

An infiltration gallery is a modification of a dug well where the ground water at moderate depths is intercepted by galleries across the line of flow. The gallery may range from an open ditch, leading the water away, to conduits of masonry, wood, iron or vitrified pipe provided with openings, surrounded by stone or gravel, to permit the entrance of water. The galleries are usually constructed in open trench and are arranged to lead the water to a pump well. Similar galleries at right angles to the direction of flow can occasionally be used to increase the yield of dug wells.

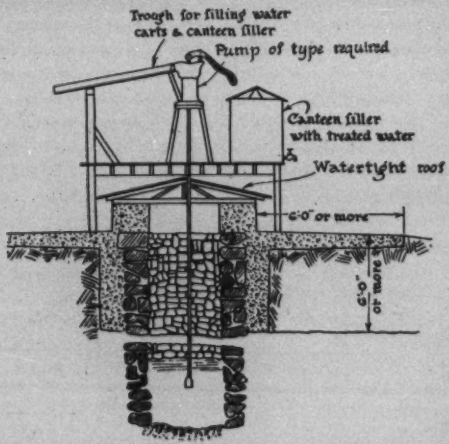
Trough for filling water carts & canteen filler
Pump of type required
Canteen filler with treated water
Watertight roof
6'-0" or more
6'-0" or more

FIG. 7. — DEVELOPMENT OF WELL.

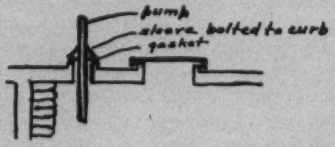

FIG. 8. — CONCRETE WELL COVER.

Driven Wells. The tubes are 1 to 12 in. in diameter (2 in. is most common) and the screens 2 to 4 ft. long. New sections are screwed on as the pipe is driven. Open-end wells are constructed by driving a plain pipe which may or may not have a heavy driving shoe attached. The material inside is removed by a sand pump or by a water jet forced down a small pipe inside the drive pipe. The pipe is perforated either before driving or by special tools after driving. A perforated strainer section should always be used even if the bottom of the well is open. Three-eighths-inch holes about four inches apart are often suitable.

Driven wells are suited to loose sand or gravel. One disadvantage is that the screen may become clogged and grit may be drawn up and score the working parts of the pump. If a well becomes clogged after use, it can sometimes be cleaned by forcing water into it under pressure. It may be necessary to pull and redrive the casing, perhaps with a new strainer. Wells of the larger diameters are best adapted to obtaining large supplies from the stratified drift or other sand or gravel deposits. Driven wells are less suited to till because the bowlders make driving difficult and the yield is insufficient for a satisfactory supply. If several wells are to be driven, they should be in a line across the direction of underflow, so that the maximum yield may be intercepted without interference among the wells. In the stratified drift, the wells should be 8 in. or more in diameter with holes ¼-in. or larger. They should be pumped vigorously for a time to get out the sand and leave a pocket of clean gravel around the intake.

In driving, a 100-lb. hollow cast-iron weight slides on a rod projecting vertically from the tube. The weight is raised by two ropes passing over pulleys and dropped on a cap or clamp fitted to the upper section of the tube. It is important that the tube be absolutely vertical. Until the first two sections are driven, they should be constantly checked by a plumb line from several different angles. They can be driven in unconsolidated material by three to five men at a rate of 3 in. to 1 ft. per min., an average time for wells 20 ft. deep being less than one hour (3 to 5 man hours). A dug well under similar conditions may take 50 times as long, and it will be difficult to isolate undesirable upper water. The tubes can usually be withdrawn without difficulty. If the stratum is soft, a few rotations while applying upward force may free the tube; or the tubing may be levered up with a heavy timber applied to the clamp and pivoted near the tube. A better method is to use screw or hydraulic jacks. If these fail, it may be assumed that the tube is bent and, if recovery is important, it must be dug out.

Bowlder-strewn deposits may make several trials necessary before a suitable location is found, although fragments may often be split or pushed aside by the point. Bending of the tube is indicated by resistance to rotation. Progress can be facilitated in compact clays by introducing a little water in the tube or around its exterior, and it is desirable to rotate the pipe a fraction of a turn at each blow in tough ground. The following characteristics will assist in recognition of strata*:

Soft Clay — rapid driving, dead blow without rebound, slight but decided resistance to rotation.

Tough Indurated Clay — slow driving but appreciable descent at each blow, no resonance, weight often rebounds, considerable resistance to torsion.

Sandy Clay — intermediate between above.

Fine Sand — hard to penetrate, dry or wet, some resistance to torsion with a slight gritty sound, weight often rebounds with a dull resonance.

*From Thompson.

Coarse Sand — easily penetrated, especially when saturated, progress irregular, rotates easily with very gritty sound, no rebound of weight.

Gravels — easy but irregular driving, rotates with gritty sound and irregular movements as pebbles are pushed aside.

Bowlders and Rock — little or no progress, rebound of weight (and sometimes of pipe), loud resonance, easily rotated unless out of vertical.

Entry into water-bearing strata usually accelerates progress except in fine sand.

If below the estimated water table and if water stands within 15 or 20 ft. of the surface, a pump can be attached and a test made of the yield. If the lower part of the pipe is plugged with fine material, it can be cleared by lowering a string of ½-in. pipe, attaching a hand pump and running water in between the tube and pipe, steadily lowering the pipe while pumping. A simpler method is to repeatedly raise and lower the ½-in. pipe after the tube has been filled with water. If the thumb is held over the top during the upward motion and removed during the quick descent, a jet of muddy liquid can be expelled at each down stroke. A small ball valve on the lower end of the pipe would be a better arrangement.

As a safeguard against pollution the casing should be thick enough to resist corrosion, should have tight joints and should be carried above ground level. If located in a stream valley, casings should be carried above flood levels. The importance of tight joints must be emphasized. Joints admitting air will cause the pump to lose its water the moment pumping is suspended. They should be carefully cleaned, bruises and burrs removed, painted with red lead and tightly screwed. Where heavy driving has endangered the tightness, the whole string should be twisted whenever the point reaches resisting material. Two or more wells can be grouped in a common suction although, if the water is 15 or 20 ft. below the surface, some trouble may occur from unequal suction and the difficulty of exhausting air from the horizontal pipes unless the pump is capable of a short high-speed run. The temperature of the different tubes is often an index as to whether they are working or not, and a rod or walking stick placed between the pipe and the ear will usually detect flowing water.

Drilled Wells. Drilled wells are usually unsuitable for use in forward areas on account of the time, special equipment and skilled labor required, and their visibility. The only type considered here is that using the percussion drill, with a portable rig, as commonly used for oil. The diamond drill, the hydraulic rotary and jet, the California or "stovepipe" method of driving overlapping, riveted-steel casings, and our so-called "bored well," as put down in soft material with augers, will have little use.

The percussion drill has a long steel bar with a sharp hardened bit which is worked up and down by a gasoline or steam engine. At intervals the drill is withdrawn for sharpening and the débris removed with a sand pump or bailer. The portable drilling rig consists of a heavy frame work mounted on wheels which may be moved with horses or tractor or under

its own power. A derrick stands at the front and can be folded back over the machine. It can be supported by the truck or guyed to stakes or dead men. Manila, hemp or steel-wire cables are used. Weights of portable rigs vary from 5 000 to 20 000 lbs., the usual weight being about 15 000 lbs. They can be used to depths of 1 500 ft. to 2 000 ft. or more, but if a supply is not found within 300 ft. in granitic rocks, it is better to try a new locality.

The "Star" portable machine was adopted by the British and United States Armies during the last war. Star Rig No. 22, which appears to be the most suitable type, is designed for a depth of 800 ft., but in practice is usually kept within 500 or 600 ft. While far from intricate, expert operators are required for high-speed operation. A boiler is mounted on the rig, a reversing steam engine transmitting power to a band wheel about 5 ft. in diameter. The tools are worked by a walking beam and a 1¼-in. diameter manila drilling cable wound on a drum. The bits are dressed steel with the bottom edge nearly flat, breaking down rather than cutting the rock. Tool joints are screwed up by jack levers or by driving up wrenches with heavy sledges. A collar-joint casing is used, with joints butted to better stand heavy driving. Approximately 20 ft. of water are maintained in the hole, about 300 gal. per day being used in a dry hole where little water is absorbed by the beds.

Rates of drilling 4 to 6-in. holes are given by the *U. S. Geological Survey* as follows: in shale, soft sandstones and similar materials, 30 to 50 ft. a day; in hard sandstones 15 to 25 ft. a day; in clay and other unconsolidated material 75 to 100 ft. a day; in hard, tough lavas 2 or 3 ft. a day. Fifty-two wells drilled in Macedonia in 1917, 6 to 10 in. in diameter with depths varying from 65 to 680 ft. gave an average depth of 178 ft. and 14 days per well (8.9 drilling days and 20 ft. per drilling day).

Increasing the Yield of Wells. In clay and the denser varieties of bowlder clay and till, water is given up slowly and the amount entering is more or less proportional to the area of surface exposed in the well. This area varies with the diameter, six times as much surface being exposed in a 3-ft. as in a 6-in. well, hence large wells are desirable. They are also desirable in rocks in which the water occurs in pores, rather than in open passages, and at the same time they increase the chance of striking an opening. The depth of dug wells is important in providing increased storage. In some cases, where the water table has sunk, the deepening of the well will be sufficient.

In deep wells the use of dynamite shatters the surrounding rock and may result in connection with other water-bearing crevices. Dynamite is most effective in hard brittle rocks, such as limestone, and least effective in soft tough shales.

Packing with gravel is useful when the material is so fine as to clog the flow. Pebbles may sometimes be dropped into the well and forced out into the surrounding clay with a drill until a pocket is produced permitting

flow. Yield and specific capacity of wells in unconsolidated sands may often be increased by removing sand from around the strainer and substituting selected graded gravel. A coarse strainer will be used and the effective diameter of the well becomes that of the gravel pocket. The method consists of pumping out sand through an inner casing and simultaneously feeding in gravel between an inner and an outer casing. This method is most applicable to shallow wells in fine sands.

A gradual reduction in the flow of a deep well may be due to a drawing off of the general supply in the area, to deterioration of the well from clogging of the screen, entrance of sand to working parts of a pump or leakage of the well from corrosion of the casing.

Rain and Snow Tanks. If rainfall is low, there are no rivers, and suitable water cannot be obtained from wells, tanks collecting rain from roofs can be used. Aden is mainly dependent on the ancient rain-water tanks on the hills above the city, and Jerusalem, until 1918, depended largely on the tank system.

The first rainfall should be rejected. After long storage it becomes objectionable due to the growth and decay of algæ. The unpleasant vegetable taste of long-stored rain water cannot be destroyed by boiling. Water should be withdrawn only with a pump. The tanks should be of masonry or concrete, tightly roofed over and screened, to exclude light, dust, insects and small animals.

In the hot, dry plains of the Ural provinces of Russia the only drinking water in the hot season is obtained from snow packed in underground chambers.

Evaporators. Any boiler or condenser may be used, but it is costly in fuel, using 1 lb. of coal to 7 to 10 lbs. of condensed water, and the boiler needs constant cleaning. Four plants were used by British troops on the Mediterranean Coast west of the Nile with capacities ranging from 7 000 to 22 000 gal. per day, with an average efficiency of 2 150 gal. per ton of coal. Multiple condensers can be arranged, giving 35 lbs. of water per lb. of coal. Steam generated in one unit is used to evaporate water in another, in a plant of four units.

Emergency Expedients. In many tropic jungles, certain creepers whose foliage is confined to the tops of forest trees draw water up through hollow stems. If cut near the bottom, the suction will carry the water up out of reach. By cutting out strips higher up, appreciable amounts of water can be obtained. Watermelons, if abundant, will support men and animals. During the Philippine Insurrection, we found the water of the green cocoanut to be clear and cool, little resembling the so-called milk in the ripened nuts.

Pumping. The windlass with one or two buckets, is the most common method of raising water. It is subject to the objection that it facilitates contamination of the water in the well. Hand-force pumps may be used for shallow wells. For deep wells, if the water rises high enough, the best method for raising water is the electrically-driven centrifugal pump either fixed on supports across the well or in a chamber cut within suction lift of the water.

A canvas belt elevator can be quickly installed in an open well. An endless 8-in. canvas belt weighing 0.346 lbs. per yd. is used, running over a 15-in. drum, the bottom loop immersed in the water 6 in. from the bottom of the well when at rest. Water is taken off by a scraper at the top or, at high speeds, by centrifugal force. These elevators were used in the British forces for delivering 1 000 to 2 000 gal. per hour at depths of 40 to 200 ft. The chief disadvantage was a lack of durability in the belts. Slip can be avoided by tacking a 4-in. strip of canvas around the middle of the pulley and, for the shallower wells, using two or more belts superimposed. A 3- to 5-h.p. gas engine is suitable for power.

The Chaine Helice, a French patented device, is an endless chain usually 28 mm. in diameter surrounded by coils of wire which move with, and are attached to the chain. The chain passes over a grooved pulley geared for either hand or power operation. A lower pulley hangs suspended in the chain and submerged. A 206.6-ft. chain is required for a depth of 100 ft. The water is held in the wire coils by capillary attraction, and as the spiral wire passes over the grooved pulley at the top, it opens out slightly, throwing the water off by centrifugal force. The chain should not touch the sides of the well. The pump can be used to depths of 150 ft. by hand and 300 ft. by power, the greater depths requiring smaller cells in the chain. There should be 2 ft. of water over the top of the lower pulley and 1 ft. below its lowest point. The output varies with the size of chain, giving 10 to 50 g.p.m.

The amount of water that can be lifted by a plunger pump depends on the diameter, stroke and speed. With a 6-in. hole, a 4-in. rising main and a $3\frac{1}{4}$-in. pump barrel will give 200 g.p.m. With a 6-in. rising main and $5\frac{1}{4}$-in. barrel, 500 g.p.m. may be obtained. The suction lift should never be greater than 20 ft. Under some conditions it will be necessary to change the elevation of the pump to adjust to varying levels of water, the practicable speed decreasing as the depth increases. The stroke of reciprocating pumps will vary from 6 to 40 in. with speeds up to 40 r.p.m. Owing to shock and vibration, maintenance charges will be high.

The centrifugal pump may be of either horizontal- or vertical-shaft type. The horizontal is standard and should be used when possible. The vertical type has the advantage that a short belt or direct drive can be used on the surface and power transmitted to the pump by the shaft. It will operate under water, and this is convenient where large fluctuations of the water table occur, but a considerable loss of efficiency takes place in friction losses in the bearings supporting the shaft.

When electrical power is available, centrifugal pumps are usually directly connected to the motor. A saving in power is effected by discarding the belt, but, as the motor has a fixed speed, it must be designed to fit the conditions.

The capacity of a centrifugal pump varies with the total head (including suction lift), the speed, and the design of the impeller. Small pumps run at higher speed than the larger ones, and the same pump must run at a higher speed for greater heads. Average figures for a single-stage belt-driven pump are as follows:

Size of suction and discharge in inches.	Normal capacity in gals. per min. at 40 ft. total head.	Recommended h.p. for each foot of lift at normal capacity.
1	20	0.02
2	100	.06
2½	150	.085
3	225	.114
4	400	.20

A centrifugal pump is not ordinarily operated under more than a 17-ft. suction lift, and it may be necessary to reset the pump from time to

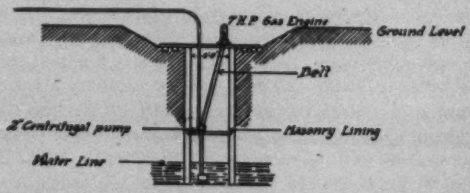

FIG. 9. — TYPICAL CENTRIFUGAL PUMP INSTALLATION.

time to keep it within 17 ft. of the water level. A 10- or 12-ft. suction lift (or less when possible) results in more satisfactory operation. If it can be installed below the level of the water so as to have a positive head on the suction, its operation is more satisfactory.

It is necessary to prime centrifugal pumps, either by extracting the air from the top of the pump casing, or by admitting water under pressure when the pump is not running and allowing the air to escape through a valve at the top of the casing. When pumping from driven wells, a vacuum chamber should be inserted in the suction pipe with an ejector for exhausting the air from the top of the chamber. Dissolved air will separate from the water and stop the pump unless this precaution is taken for its removal. In field installations where such provision is impracticable, it may be necessary to stop the pump from time to time and remove the accumulated air.

The portable gasoline-engine unit adopted by the army consists of a 4-cylinder, 4-cycle engine of 18 to 20 brake h.p. at 1 200 r.p.m. direct-connected to a single-stage 2-in. double-suction centrifugal pump, and

mounted on a base of the skid type. Under normal conditions it should have a capacity of 100 g.p.m. against a 60 ft. head (including suction).

In a form of centrifugal pump, called the deep-well turbine, the shafting is enclosed in the discharge pipe and the apparatus designed to fit inside a well casing. As the impellers are small a number of stages are provided — one for each 20 or 30 ft. of lift. It is supported at the ground and hangs free in the well. Power may be applied by a belt or directly by a vertical motor.

The air-lift pump is adapted to supplying large amounts of water from great depths. Compressed air is forced down an air pipe and delivered near the bottom of a discharge pipe where it expands and rises, bringing water with it. The pressure used ranges from 20 to 100 lbs. per sq. in. and is usually $^1/_5$ to $\frac{1}{4}$ lb. per ft. of lift. There are no moving parts to wear and it may be operated from a distant air compressor. The air lift pump equipped with a portable air-compressor is recommended for use with tube wells in the theatre of operations.

Distribution Systems. Direct pumping into pipe lines has many objections and should preferably not be employed. In case it is necessary, a relief valve must be placed at the pumping station to provide for the possibility of valves being shut on the line. Storage should usually be provided in the form of a raised tank or reservoir to provide a constant head, to prevent water hammer and to provide for variations in the demand. If pumps are used, duplicate sets should be provided for use in case of breakdown. Telephone connections are essential to the efficient working of a long pipe-line.

One-inch, 2-in. and 4-in. pipes will have a large use and should be standard. The 4-in. size can easily supply a division with 100 000 gal. per day and, by repumping, the water can be carried forward indefinitely. With trained men four miles of 4-in. pipe can be laid in a day* which is as fast as an army would be likely to advance against resistance, and the pipe can later be buried. The 2-in. and 1-in. sizes are suitable for laterals to water points and other distribution. The British forces in France at times supplied $\frac{1}{4}$ to $\frac{1}{3}$ mil. gal. per day to water points with 15 to 20 miles of pipe line. Occasional need may arise for 6-in. or larger sizes in bringing supplies a considerable distance. Screw-joint steel or wrought-iron pipe was largely used in France. It was found to be satisfactory, except that occasional trouble developed from crossed threads or insufficient screwing, when laid by unskilled men. A better form of quick-joint steel would be of value. Specials required vary with conditions but should include 45° and 90° elbows, tees, bushings, plugs, nipples, valves, couplings and saddles.

Pumping stations should be easy to install and simple to operate. Steam is rarely used because of the heavy equipment required and the fact that the smoke is easily picked up by the enemy air service. Electricity

*Parsons gives a figure of one mile per day under actual battle conditions.

has many advantages where its use is possible, but the standard fuel in the theatre of operations is gasoline. The pumps should be housed in shelters large enough for two men and with such heating as required to prevent water jackets from freezing. It is usually possible to locate repair shops and needed supplies at the station.

In forward areas, when natural protection is not available, splinter-proof and, in some instances, bomb-proof construction is desirable. Camouflage, by placing in a ruined building or other means, should always be used.

Storage should be provided both at the source of supply and at the point of distribution. The amount depends on the variation of supply and demand. In case water is moved forward by tank truck or light railway and the supply is sufficient for the average demand, storage must be sufficient to supply the difference between the average and the maximum.

Transport of water during a forward movement is normally by the 500-gal. tank truck from rear to forward areas, pending a development of local supplies or supplementing them. In rapid forward movements the tank trains are assigned to Divisions and Corps, but normally operate under army control from water sources to water points established by the Division or Corps. The engineers concerned should chlorinate supplies at the water point as a matter of standard practice, unless it is known that no pollution exists. Following the advance, water supply troops will move forward to make available captured supplies and develop new sources.

When suitable conditions exist, light railway tank cars of 2 000 gal. capacity may be used to deliver within reach of the organization means of distribution — the 110-gal. water cart or 5-gal. cans carried by wagon or by pack mule.

Water Points. Water points are points for storage and distribution to organizations. They should be as far forward as is consistent with concealment from artillery fire and air observation, and may be located at varying distances from the front lines, at times actually in the trench system and under other conditions as far back as five to seven miles. They should be located near the center of gravity of military population of the area to be supplied. Near the front they make use of the mobile purification units, canvas reservoirs and horse troughs, hand pumps and small power pumps as required. Farther to the rear, steel or wood storage tanks may be used or supplies may be piped. Both men and animals must be supplied and separate facilities should usually be provided. They should be near a main road but not on it, and traffic should enter and leave without turning.

Figures 11 and 12 give typical arrangements of canvas basins and troughs for a water-cart and canteen filling point and a horse water point. The standard canvas basin is a flat waterproofed canvas 20 ft. square. If used in a rectangular timber frame with a base 12 ft. square and sides 4 ft. high, its capacity is about 4 000 gal. These can be elaborated, or adjusted to available material. Timber, steel, or concrete can be used for the tanks and troughs of a more permanent installation.

A tank-cart filler in the simplest form may be a hose and hand pump delivering from a canvas basin sunk in the ground. A support should be constructed for the hose to keep it from becoming soiled. The canvas basin should be covered with canvas or some other type of roofing (timber, tarred paper, or corrugated iron) to keep out dust and other forms of pollution, and to prevent reflection visible from the air. The canvas for the basins should be waterproofed — but unwaterproofed canvas, although leaking considerably at first, will gradually tighten up. The road at the filling point should be paved with gravel, rock or timber and the area drained. Suitable methods of sterilizing the water should be provided if necessary. Faucets of canteen fillers should be small enough to fit into the canteens.

Horse troughs (see Fig. 10) need not be supplied with sterilized water although clean water is desirable. Streams are used, when available, by pumping into the troughs. The ground in front of the troughs should be

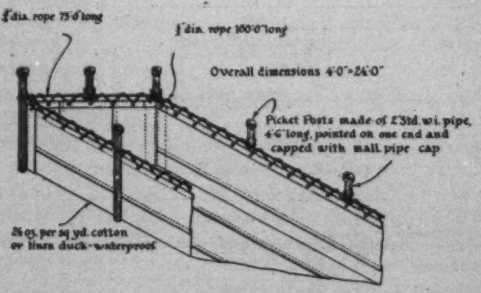
¾" dia. rope 75'-0" long
¾" dia. rope 100'-0" long
Overall dimensions 4'-0"×24'-0"
Picket Posts made of 2½" wt. pipe, 4'-6" long, pointed on one end and capped with mall pipe cap
8½ oz. per sq. yd. cotton or linen duck—waterproof

FIG. 10. — CANVAS HORSE TROUGH.

paved for about 12 ft. Guard rails are essential and chicken wire can be used to prevent gnawing wooden frames or canvas. In estimating the troughing required, allow four feet frontage per horse and five minutes for each animal to water.

In stabilized situations water may be supplied for laundries, lavatories and baths. The lavatories usually consist of a pipe with faucets at intervals of 2 to 2½ ft. placed over a shelf and V-shaped waste trough. Large, centrally located bath and delousing plants are operated by the Quartermaster Department but there should be many opportunities to set up the 8-head showers. These, with heater and piping, should be available in the army dump.

Filling stations for locomotives and tank cars should be of about 25 000 gal. capacity and so arranged that engines can water without being detached from trains. Locomotive filling tanks should be about 10 or 15 miles apart on main lines and at engine terminals and yards. Side tracks must be provided so that tank cars can be filled without impeding main-line traffic.

Tanks are usually of steel or timber, the circular tank of 3-in. timber with iron binding-rods and turn-buckles being particularly suitable, as it can be knocked down for shipment. Posts for such a tank should be 8 x 8 in. Four-inch piping should be used with hose connections for filling tank cars and locomotives. The bottom of the tank should be about 16½ ft. above track level.

Water discipline is of the highest importance. Guards should be available to superintend the filling of storage basins and canteen fillers, to see that water is chlorinated, to prevent waste and for traffic control in the absence of military police. Discipline at animal watering points should provide for admission at one time of sufficient animals to utilize the full

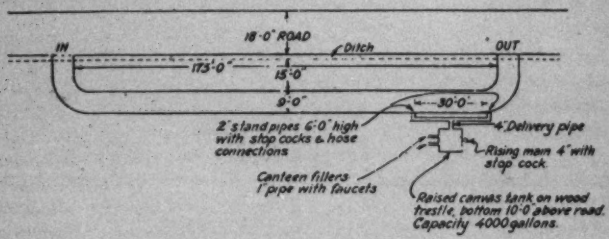

FIG. 11. — TYPICAL WATER POINT.

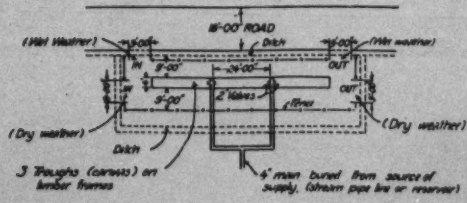

FIG. 12. — TYPICAL WATER POINT (ANIMALS).

length of the trough, to see that bits are removed, and that no animals attached to vehicles are permitted to water.

Proper use of signs in connection with water distributing points is of the greatest importance and they should be placed at road junctions and other points within a radius of from 500 to 2 000 yds. as well as at the water point.

Cantonments. The water supply of cantonments for the concentration of large bodies of troops is a special problem for any particular site and requires the care in design which would be given to the water supply of municipalities.

Provision should be made to deliver 55 gal. per capita per day at all

seasons of the year and all hours of the day. This includes an allowance of 15 gal. for animals. As there is about one animal for three men the net allowance for men is 50 gal. This amount, 80 per cent. more than was provided in British and French cantonments, was allowed by the Construction Division during the World War. About 25 per cent. of the cantonments exceeded this amount, and about 30 per cent. used less than 30 gal. per capita per day. The amounts used depended much upon the attention given to leaking pipes and defective fixtures. In one instance the excess of water used was due partly to a central heating plant with no return system, and a loss of 500 000 or 600,000 gal. per day occurred in this item alone during the winter. In the 20 miles of mains in the average cantonment the leakage amounted to from 100 000 to 200 000 gal. per day. Tent camps without fire and sewer systems require a maximum of 30 gal. per capita per day, but if conversion to a barrack camp is contemplated the 55 gal. figure should be used.

The pressure in the distributing mains should be between 60 and 85 lbs. per square inch, (the larger figure when appreciable differences in elevation exist in the cantonment) in order to supply efficient fire service. The limit of 85 lbs. was set on account of the design of wood-stave pipe for that pressure.

The pipe used for distribution mains should be largely machine-wound wood stave which may be shipped, made up and supplied at a lower cost than any other material, about 60 per cent. of the cost of cast iron in 1918. If the cantonment is supplied at one end and pressures of 60 to 85 lbs. are maintained, two 12-in. mains are required throughout its length. If the cantonment is supplied at the center with looped lines to each end two 10-in. mains are required. If elevated storage is used sufficient to tide over peak loads and maintain the required pressure, friction losses in the mains are reduced and smaller pipe can be used. The mains must be computed for supplying the peak load with the required pressure and to deliver a fire flow of 2 000 g.p.m. at 50 lbs. pressure at hydrants at the most distant part of the system. The 1918 specifications called for 2½-in. hose with small nozzles and close spacing of hydrants.

In one instance (Fort Humphreys, Va.), where provision was made for 55 gal. per capita per day, water was taken 1¼ miles by gravity from a small impounding reservoir through 22-in. wood-stave pipe to a 250 000 gal. sedimentation basin and rapid sand filter (capacity 2 000 000 gal. per day) where the water was chlorinated and pumped through two 12-in. mains by three electrically-driven centrifugal pumps to a 300 000 gal. elevated tank about 110 ft. above the camp. One internal-combustion engine and pump was provided as a reserve.

The cost of cantonment installations averaged $11 per capita in 1918 while the cost of the average civilian installation for a city of 40 000 was about $50 per capita — (Maury, *Engineering News*, January 3, 1918), the low cost being due to the use of wood-stave pipe and the grouping of the

15 000 fixtures in a few locations. Water purchased from existing systems cost between 4½ and 15 cents per 1 000 gal., the higher rate including pumping and chlorinating.

One of the most interesting features of the War was the advance of the British from Egypt to the Suez Canal and through the Sinai Desert and sand-dune coast country to the capture of Gaza and Beersheba in November and of Jerusalem on December 11, 1917.

The only reliable source of water in the Suez Canal area was the Sweet Water Canal, flowing from the Nile to Ismaïlia on the west bank of the Suez Canal and thence to Suez and Port Said. This required purification. Wells to a depth of 300 ft. east of the Suez Canal gave nothing but salt water, so water from the Sweet Water Canal was siphoned to the east bank for the supply of the defence lines which were occupied until the capture of El Arish in December, 1916. Filters were installed at Kantara, drawing from the Sweet Water Canal and delivering 250 000 gal.* per day to the east bank, and water was sent forward to El Arish in a line of 10 and 12-in. pipe.

There was difficulty in obtaining labor to screw the pipe and progress was slow at first. The pipe was covered with sand (which often blew off and in some cases blew out from underneath the pipe) to protect it from temperature changes, and expansion $\frac{1}{m}$ joints were used at the end of each 3 km. (1.86 mile) section, which practically ceased to act as such when the pipe was covered and filled. The line was completed to El Arish from Kantara, 155 km. (96 miles) in February 1917, an average of 1.25 km. (¾ mile) per day.

The railway was extended to Rafa in March 1917, and the pipe line followed. For the attack on the Gaza-Beersheba line the pipe lines were extended from Rafa to Imara, supplying filtered Nile water a distance of over 150 miles.

DATA ON KANTARA-IMARA PIPE LINE, 1917–18, 142.6 MILES
(DATUM 10 METERS BELOW SUEZ CANAL LEVEL)

	Elevation Meters.	G. P. H. Pump Capacity.	Storage thousand gal.	Engines. No. H.P.	Pipe to next station. in.†	Dist. km.
Kantara....	11	43 300	500	4–90	12–10	
Romani.....	10	39 990	500	4–75	12–10	41
Abd.....	18.2	33 570	500	4–75	10–12	76
Mazar.....	19.8	21 990	500	4–75	10–8–10–12–8	113
El Arish....	27.3	28 400	750	2–56	8	155
Rafa.....	78.5	21 000	1 000	2–66	6	187
		5 000		2–20		201
Imara						229½

(Elevations to floor of reservoirs)

*Figures quoted here are from the report of the Royal Engineers on Water Supply and are assumed to be Imperial gallons.

†Sizes used in single line.

The piped supplies were supplemented by water from railway tank cars, and Royal Engineers Field Companies were organized into 12 well units, each carrying lift and force pumps, water troughs, canvas tanks, tools to dig shallow wells and lining material. The spear point, so-called, a variation of the Norton tube well,* was a 2½-in. steel tube cut in 5-ft. lengths. The lower section was fitted with a steel point and freely perforated, the perforations being covered with fine gauze or wire cloth. They were supplied with special couplings to connect with the service force-pumps and, under favorable conditions, could produce up to 600 gal. per hour. The water was stored in canvas tanks supported by walls of sand bags.

The wells of Beersheba have been famous since Abraham watered his flocks there, and Gaza has innumerable wells of good water. Beyond this line reliance was placed largely on existing deep wells fitted with power-driven pumps delivering 1 000 to 6 000 gal. per hour.

The water supply of Jerusalem, when the army entered in January, 1918, was obtained from the following four sources:

1. Rain water in underground cisterns obtained from roofs and court yards, limited in amount and questionable as to quality.

2. Rain water in ancient reservoirs — surface drainage from the upper part of the town and unfit for human use.

3. Water pumped from springs near the Pools of Solomon, eight miles southeast of the city, supplying 40 000 gal. per day by an ancient aqueduct.

4. Springs of the Pool of Siloam, below the city, and polluted by its sewage.

In normal years the supply barely met the demand, and the springs in the Wadi Arrub, six miles south of the Pools of Solomon were developed to supply normally 300 000 gal. per day (in October this was 150 000 gal. per day) with a storage of 4 000 000 gal.

A fact of interest in connection with Allenby's capture of Jerusalem is noted by John Buchan in Vol. XXI of his *History of the War*. For centuries there had been current an Arab prophecy concerning a deliverer from the west — that he would bear the name of a prophet of God, that he would enter Jerusalem on foot and that he would not appear until the Nile flowed into Palestine. To the peasants of Judea this prophecy now seemed to be fulfilled, for the name of the English general was, in Arabic, El Nebi or the prophet, he entered the city on foot, and his men had come bringing with them the waters of Egypt.

VI. Purification.

Previous to the last war little had been accomplished toward organized sterilization of water supplies in the field. During the Spanish War in 1898 officers of the regular army had a reasonable knowledge of camp sanitation

*Our driven well (the English tube well) was invented and patented in England by Norton, in 1868 for use in the Afghan Campaign.

and the discipline to enforce sanitary regulations. The militia and volunteers paid a high toll in deaths from water-borne diseases. In the Philippines in 1901 a small portable sterilizer was in use. While the water was insipid and warm, deaths in the army from the severe cholera epidemic of that year were few and almost entirely due to individual infractions of the sanitary regulations. During the Great War the hypochlorite capsule and the Lyster bag, the purification truck and typhoid inoculation undoubtedly saved many thousands of lives.

A comparison of the number of deaths from disease in different wars may be of interest. For each 100 killed in battle, there died from disease in the Mexican War 726; in the Civil War 200; in the Spanish War 520; and in the World War 36. (This figure for the World War includes the influenza epidemic.)

Requirements as to Quality. Natural water contains inorganic and organic matter in suspension (as sand, silt, leaves, animal tissue, algæ, insects) or in solution (as oxygen, nitrogen, carbon dioxide, ammonia, carbonates, bicarbonates and sulphates of calcium and magnesium, sodium chloride, nitrates, etc.). Much suspended matter renders water undesirable or unfit for drinking. Silt acts unfavorably on the intestines while organic matter is generally in the process of decay and may cause disease. In general, mineral constituents are unobjectionable in water for drinking, unless present in sufficient amounts to create an objectionable taste.

Bacteriological tests usually consist of a determination of the presence of Bacterium coli communis (B. coli) which is abundant in the intestines of men and animals and usually indicates contamination by sewage. If organisms of the B. coli type are absent and the total number of bacteria is not too high we can definitely say that the water is safe. If B. coli are not entirely absent it cannot as definitely be said that the water is dangerous, but if they are persistently present in small amounts of water, as 1 c.c., the water is likely to contain human waste and is unsatisfactory.

The following items are usually determined and the figures are typical. The quantities are expressed in parts per million by weight (milligrams per thousand c.c.).*

	Good Water	Sewage
Total solids	50.0	700.0
Organic matter (loss on ignition)	30.0	200.0
Inorganic matter (fixed residue)	20.0	500.0
Chlorine as chlorides	3.0	40.0
Free ammonia	0.010	25.000
Albuminoid ammonia	0.100	10.000
Nitrogen as nitrates	0.200	0.100
Nitrogen as nitrites	0.000	0.005
Oxygen consumed	0.5	40.0
Bacteria in 1 c.c.	50.	1 000 000.
B. coli in 10 c.c.	0.	5 000.

*Table from Merriman.

As sodium chloride often amounts to 1 per cent. of the urine, the presence of an abnormal amount of chlorine usually indicates sewage pollution. The chlorides may, however, be soluble constituents of the rocks traversed by ground waters, and the normal amount increases with proximity to the coast. Two hundred and fifty p.p.m. give a salty taste, while 60 p.p.m. may give boiler trouble. High chloride, ammonia and nitrite point to considerable recent contamination. High chloride with low ammonia and nitrite point to a rock source or remote contamination or efficient filtration (chloride is not removed by filtration).

Albuminoid ammonia is an indication of undecomposed organic matter, animal or vegetable, and is derived from organic matter containing nitrogen. It is usually the source of free ammonia so the amounts present are likely to vary inversely and the total ammonia content should be considered. High albuminoid and free ammonia and chloride point to sewage pollution. High albuminoid with low free ammonia and chloride point to vegetable contamination. Free ammonia is that given off in boiling and is derived from organic nitrogen which has passed through the first stages of mineralization. Its presence does not condemn water as there are other possible sources than sewage.

Nitrites are the next step in mineralization; they are unstable and not ordinarily found unless active chemical change is going on. They are always an indication of danger, usually of recent organic pollution. Nitrates are the final stage of oxidation in which the nitrogen has been completely mineralized. They may be harmless products of organic nitrogen and indicate remote sewage pollution, but other sources are possible, as they may occur in ground waters from mineral sources.

"Oxygen consumed" serves as a means of comparing relative amounts of carbonaceous organic matter and other oxidizable constituents of various waters. The "solid residue," after evaporation on a water bath, is usually white from a good water. A reddish or brown color commonly indicates iron. If the residue blackens on heating more strongly (to 180° C.), organic matter is indicated (probably of animal origin if the odor is disagreeable). A lens will assist the examination. Carbonates may be determined by treating with hydrochloric acid.

Hardness, estimated by the power to destroy standard soap solution, is mainly due to sulphates, carbonates and bicarbonates of calcium and magnesium. Degrees of hardness are expressed in parts per million or grains per gallon of calcium carbonate or its equivalent; under 3 grains per gallon (50 p.p.m.) soft, over 50 p.p.m. hard, over 100 p.p.m. very hard. Water containing 15 grains per gallon (250 p.p.m.) is unsuitable for washing or use in boilers. A hard water is usually unobjectionable for drinking unless magnesium salts (as the sulphate) predominate. "Temporary hardness," caused by the bicarbonates, can be removed by boiling which liberates the carbonic acid holding the carbonates in solution, or by adding lime, $Ca(OH)_2$, which forms insoluble calcium carbonate with the carbonic

acid. The sulphates cause "permanent hardness" which can be removed by adding sodium carbonate (lime must be added in case of magnesium sulphate) precipitating sodium sulphate.

Turbidity may be produced in some waters by exposure to the air, as where, on the liberation of carbonic acid, bicarbonate of iron is changed to an oxide which is precipitated. Liberation of carbonic acid from waters containing an excess of calcium bicarbonate will precipitate calcium carbonate, often deposited around a spring as a light porous limestone called calcareous tufa. Silica and other substances more soluble in hot than in cold water may be deposited around hot springs. A yellow color is often due to organic matter, usually sewage, although a red brown color may be due to peat. Efflorescence of various salts often appears on soils or rocks where surface evaporation causes upward capillary circulation of the water. Iron waters are likely to cause red stains around a spring or have an iridescent oily-looking film on the surface. As a soluble salt of iron with tannic acid forms ink, iron water will be darkened by adding an alcoholic liquor matured in oak, as brandy. Iron streams may be darkened naturally by dead leaves, by contact with streams from swamps, or by joining a sewage-polluted stream, the hydrogen sulphide in the sewage forming iron sulphide.

An odor of hydrogen sulphide from cold freshly-drawn water may be due to chemical changes in the rock and pass off, leaving the water good. It may also be due to the reduction of sulphates by bacterial action and be an index of pollution. Sulphates of calcium, magnesium or sodium are at times changed into carbonates by contact with the organic matter of surface waters, liberating hydrogen sulphide. Suspicion is always justified in case of turbidity or odor, although the water is not necessarily dangerous. On the other hand, pathogenic bacteria may exist in water that is clear and sparkling.

Most good waters are slightly alkaline from calcium bicarbonate or possibly sodium carbonate. Ammonia from sewage may cause strong alkalinity. Acidity is usually objectionable (particularly when derived from mill or mine wastes), causing corrosion to lead, iron or zinc. The contact of such water with lead pipes may cause serious poisoning. Acidity may also be caused by organic acids from peat or swamp water or from decayed vegetation, or may be due to free carbon dioxide in soft water.

Biological examination with the low-power microscope determines living organic matter, usually species of microörganisms commonly called algæ, which may produce a fishy or pig-pen odor. This examination of the water or sediment may also reveal other organisms, living or dead, as aquatic insects, worms and infusoria generally, moulds, cellular tissue, plant fibres and fæcal material.

Analysis of the same water may show different results at different seasons and a knowledge of the topography and sanitary condition of the source of supply is necessary for the interpretation of an analysis. The

bacteriological examination must be made by experts; this detracts from its value in the field and adds to the importance of methods of sterilization.

Sedimentation. Sedimentation may occur by the action of gravity in any quiet body of water. Should the silt be composed of finely-divided or colloidal clay it may remain in suspension indefinitely. In water purification it is customary to use a coagulant which, forming precipitates of a gelatinous character, unites the finely-divided suspended matter into larger masses, thus facilitating removal by sedimentation or filtration. Colloidal solutions of clay, vegetable color, etc., cannot be removed by filtration unless coagulated.

The most commonly used coagulant is Aluminum Sulphate, $Al_2(SO_4)_3$. If this is introduced into water containing carbonates and bicarbonates of lime and magnesia, it is decomposed, the aluminum uniting with the water and liberating carbonic acid. "Alkalinity" is a measure of the salts that neutralize acids, usually carbonates, bicarbonates or hydrates. Water that has been treated with aluminum sulphate or other aluminum compound should contain a residual alkalinity of at least 10 p.p.m. One grain per gallon of the aluminum sulphate requires 5 to 10 p.p.m. of calcium carbonate alkalinity, or its equivalent, for complete reaction. If not present in natural form, soda ash (anhydrous sodium carbonate — Na_2CO_3) is added to bring about coagulation and prevent undecomposed alum remaining in the treated water. High alkalinity is undesirable as causing a high degree of soap consumption, and an excess of sodium carbonate may cause the floc to redissolve. If a larger amount of aluminum sulphate is added than can combine with the carbonates present it will leave an objectionable amount of alum dissolved in the water. The reaction forms aluminum hydrate, $Al_2(OH)_6$, which acts as the coagulant. Carbonic acid is set free, increasing the corrosive action on unprotected iron or lead. This fact, however, will rarely be a detriment. The amount of aluminum sulphate required varies, with the amount of sediment, from $\frac{3}{4}$ grain to 3 or 4 grains per gallon. Two grains of alum per gallon ($28\frac{1}{2}$ lbs. per 100 000 gal.) is a common average for surface waters.

The rate of sedimentation depends much on the amount of coagulant used. Where sedimentation is followed by rapid filtration, two to six hours are usually allowed. Complete clarification is unnecessary and better filtration occurs if a small amount of the coagulant is carried to the filters. If the water is not to be filtered it is desirable to allow from twelve to twenty-four hours.

Sedimentation basins may be operated by continuous flow or by filling and emptying. The first method, the water moving with a low velocity, is desirable for filter plants. The second is often necessary where basins are improvised or the water is chlorinated without filtration. The apparatus for handling alum should have special bronze or hard-rubber fittings and copper, bronze or lead pipes. Tanks may be of concrete. Particular

emphasis must be placed on the reliability of the method of feeding the coagulant in the continuous flow method as the efficiency of the rapid filter in removing bacteria depends largely on control of the coagulation. The coagulant is introduced as the water enters the basin, preferably by a series of perforated tubes distributed over a channel through which the water passes and the solution in the alum tank must be kept stirred to insure uniform strength. A low velocity in the basin (2½ ft. per minute) is obtained by increasing the cross-section area and the use of baffles insures thorough mixing. In case alum is added to the water in a basin (using the method of filling and emptying), sufficient agitation to insure thorough mixing is necessary. A trough directing the incoming water along one side of the basin will assist in maintaining circulation while the tank is being filled. Concrete is desirable for the basin but timber or tarred canvas or other materials may be used. Laboratory tests are required to determine the amounts of alum and alkalinity required.

Filtration. Sand filters are of the slow or rapid type. The time required for construction of slow sand filters eliminates any possibility of their being constructed during military operations, but where already in use they may be taken over. They operate at from 2 000 000 to 6 000 000 gal. per acre per day. Every three or four weeks the filter must be drained and the top layer scraped off. When the sand bed becomes too thin, sand must be added. The bacterial efficiency does not depend so much on the mechanical effect of the sand as on the bacterial growth in the body of the filter and the film which forms on its surface. The sand should be clean, uniform and with grains about 0.2 to 0.4 mm. in size. As the filter becomes clogged the head is increased to maintain a uniform discharge.

In a rapid sand filter (Figs. 13 and 14) the medium is a thick layer of selected uniform sand with the artificial surface-mat caused by coagulation. The sand, 24 to 30 in. deep, should be nearly pure quartz, with rounded grains and between 0.35 and 0.60 mm. in size. A certain amount of flocculent precipitate from the coagulating basin is necessary to secure proper filtration, and sedimentation for two to six hours as required. The filter units are usually small tanks of wood, steel (for pressure filters) or concrete, and require washing every six to twenty-four hours. Washing is accomplished by reversing the flow and should hold the entire sand bed in suspension, care being taken that no sand is washed out. It should clear the sand of dirt but some coagulated floc should remain in the water over the filter to form the basis of a new mat. Effective washing requires 7.5 to 15 g.p.m. per square foot applied from three to eight min. Elevated tanks are often used to furnish wash water at the required pressure. (Between one and five per cent. of the filtered water may be required for washing). Common filter troubles include the appearance of mud balls which must be removed and the clogging of the surface sand with organic matter and mud which may cause cracks in the surface mat. After wash-

ing, a certain amount of the effluent should be wasted. The sand bed is supported on a 10-in. layer of pea-size gravel overlying the underdrain system on filters with brass strainers discharging upward. On other types 12 to 20 in. of graded gravel are used.

There should be at least 10 ft. difference in elevation between the water surface in the clear-water basin and in the filter. This gives the filtering head necessary. A greater head is likely to break the film of coagulant on the sand surface. The pipe to the clear-water basin should be trapped against the entrance of air. The head is usually controlled as in the slow sand type by maintaining a constant water level on the filter, preferably the level of the water in the coagulating basin, and automatically or manually varying the pressure head in the effluent pipe by a valve. This

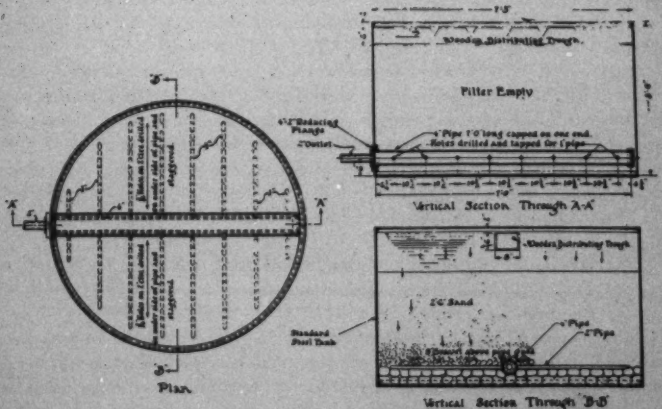
Wood's Distributing Trough
Filter Empty
Pipe 7'0" long capped on one end. Holes drilled and tapped for ½ pipe.
Vertical Section Through A-A
Plan
Standard Steel Tank
Pipe
Vertical Section Through B-B

FIG. 13. — DETAIL OF RAPID FILTER.

valve supplies a means of maintaining a constant rate of filtration. For a capacity of 100 000 gal. per day the tank should be about 7 ft. in diameter and 5 ft. or more deep. A pipe grid at the bottom with $\frac{3}{16}$-in. holes at 2-in. intervals leads off the effluent. An overflow trough should be built about 12 to 30 in. (average 20 in.) above the surface of the sand for taking off wash water.

The rate of filtration is usually 125 million gal. per acre per day (approximately 1 million gal. per day for each 350 sq. ft. of sand surface). This rate is equivalent to 2 g.p.m. per square foot. Filters usually permit a variation of 25 per cent. above or below the normal rate. Any sudden change in the rate of filtration is undesirable.

Sterilization. It has become standard practice to sterilize water by the application of liquid chlorine. This is the method used in the mobile

purification unit. In the liquid chlorine treatment a reliable feed apparatus is essential — the rate of feed being constant as all of the flowing water must come in contact with the chlorine. The solution of the chlorine is secured by a water jet which thoroughly mixes the chlorine and water. A flow of one pound of chlorine per 24 hours or 0.000694 lb. per minute treats approximately 300 000 gal. of water per day. In civilian practice 0.1 p.p.m. of free chlorine remains in the water. In military practice 0.5 p.p.m. is customary and is the minimum prescribed for the mobile purification unit. The germicidal action is due to the formation of hypochlorous acid (HOCl) on mixing chlorine and water. This reacts with the protein of the bacteria, decomposing and killing it.

Chlorination in the field in improvised installations is usually by the application of calcium hypochlorite (chlorinated lime or bleaching powder) $4\ CaOCl_2.2\ Ca(OH)_2.5\ H_2O$. On dissolving in water hypochlorous acid and calcium bicarbonate are formed. The hypochlorous acid is further decomposed into hydrochloric acid (HCl) and nascent oxygen. The hydrochloric acid combines with carbonate or bicarbonate alkalinity in the water to form calcium chloride, carbon dioxide and water. It has been assumed that the hypochlorite killed bacteria by oxidation but it is now believed that the germicidal action is due to chlorine or its derivatives rather than to nascent oxygen.

When chlorine or calcium hypochlorite is added to water the reactions may be divided into three types:

(a) Oxidation of organic or mineral matter.

(b) Direct chlorination of organic matter.

(c) Bactericidal action.

Usually the greater part of the chlorine added is required for the first reaction and the chlorine demand of this reaction must be satisfied before an excess for the removal of bacteria is available. It is common practice to make solutions of 0.5 to 2.0 per cent. strength (1 to 4 lbs. of hypochlorite to 200 lbs. of water). The essential features of its use are (*Medical War Manual* No. 6, 1918):

1. The powder should be made into a smooth paste with a small amount of water.

2. This paste should be kept thoroughly stirred.

3. Solution tanks should be kept covered.

4. Solutions deteriorate but little when standing (about two per cent. per day).

5. Period of contact with the water should be not less than 20 min.

6. A thorough mixture of the hypochlorite and water should be obtained.

7. Solution tanks should have two valves, a sludge valve on the bottom and a discharge valve on the side. The sludge should be removed daily.

8. The strength of the hypochlorite solution must be determined and adjusted with each new charge.

If the water is to be filtered the hypochlorite is added after filtration. Any turbidity reduces its efficiency. Concrete tanks with valves of special bronze are usually used for dissolving the bleaching powder. Wood can be used for temporary installations. Galvanized metal is fairly resistant as are also tin, brass, lead, hard rubber and paraffin. Wrought iron and steel corrode rapidly.

For waters overtreated with calcium hypochlorite or chlorine, sodium thiosulphate (sodium hyposulphite), can be used to remove the excess of chlorine (available in tubes containing 1 g.). This is needed only in cases where the taste of chlorine is so objectionable to troops as to cause them to drink from unpurified sources. De-chlorination is always inadvisable until the water has passed all stages where contamination is possible. There is no reason to believe that any amounts of free chlorine obtained by methods used in the purification of water are in the slightest degree harmful. It is desirable however to keep the free chlorine down to 2 p.p.m. or less. Where tests are possible it can easily be kept below 1 p.p.m.

Twenty-five pounds of hypochlorite (30 per cent. available chlorine) are required to sterilize 1 000 000 gal. of water by applying 1 p.p.m. of available chlorine. Storage or contact with air or light may bring about reactions, liberating oxygen and chlorine from the hypochlorite and reducing its efficiency. The hypochlorite is usually supplied by the manufacturer in steel drums 39 in. high by 29½ in. diameter (gross weight 750 lbs., net weight 690 lbs.). The loss of available chlorine is approximately 1 per cent. per month in hot weather and 0.3 per cent. per month in cold weather.

Small tablets of calcium hypochlorite (mixed with a small amount of sodium chloride) for individual use are available in the Medical Department in three sizes yielding 3, 17 and 35 mg. of chlorine. If kept *dry*, cool, and in a dark place they retain their strength for several months.

Either hypochlorite or alum solutions are usually applied to water entering a sterilizing or sedimentation basin by maintaining a constant head (with a float valve) on a varying size orifice. The usual head is 1 ft. Several orifices may be available in the chemical tank and that one used which gives the desired discharge. The orifices should be in a plane surface and bevelled so that the inner surface has a sharp edge. Discharge of the solution in gallons per minute may be computed by the formula:

$$7.48 \times 8.02 \times 60 \times .62 \times \frac{A}{144} = 15.5A = \text{Discharge}$$

where A = area of orifice in square inches and 0.62 = coefficient of discharge.

DISCHARGE IN U. S. GALLONS THROUGH A CIRCULAR ORIFICE—HEAD 1 FOOT.
COEFFICIENT OF DISCHARGE = 0.62.

Diameter inches	Area sq. in.	Gallons per min.	Gallons per day.
.05	.002	.0304	43.75
.10	.008	.1209	174.1
.15	.018	.2744	395.1
.20	.031	.4867	700.8
.25	.049	.7610	1096.
.30	.071	1.096	1578.
.35	.096	1.491	2147.
.40	.126	1.948	2806.
.45	.159	2.464	3549.
.50	.196	3.043	4381.

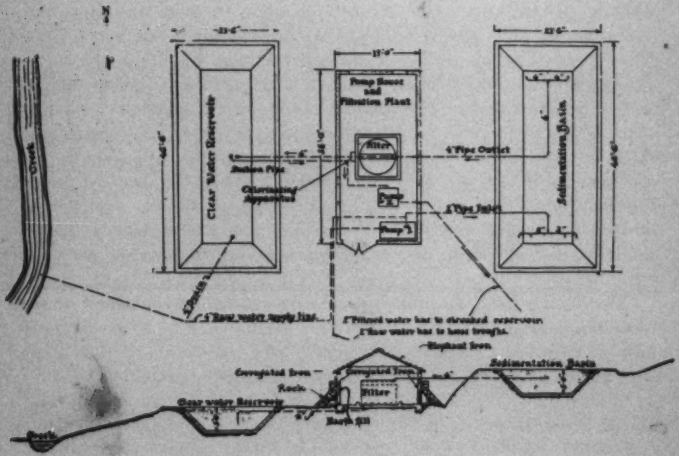

FIG. 14.—WATER PURIFICATION PLANT.

Tests for Free Chlorine. Where water is sterilized with calcium hypochlorite, a test to determine the amount of residual chlorine should be applied. Orthotolidin is the reagent used (a 0.1 per cent. solution made by dissolving 1 g. of orthotolidin in 1 litre of a 10 per cent. solution of hydrochloric acid) and the usual test is to add 1 c.c. of the orthotolidin solution to 100 c.c. of the water to be tested. Small amounts of free chlorine give a yellow, and larger amounts an orange to red color after standing 5 min. By comparing with color standards the amount of free chlorine can be estimated.

Reaction (a) as noted above requires 10 min. and the test should not be made until the chlorine has been in contact with the water for 10

min. Rarely orthotolidin added to raw water produces a yellow color (as when manganese is present). It is therefore desirable to test a sample of the water before the application of chlorine. The presence of organic matter in the water sometimes causes a false color reaction after 10 min., and readings should be made within 5 min. after adding the reagent. In very alkaline waters a blue or green color may be produced instead of yellow. Slightly increasing the amount of orthotolidin eliminates this trouble. Standard color solutions should be kept away from the light.

A method of determining the amount of chlorine needed is as follows:

(1) Rinse a canteen cup (holding approximately 1 pt.) with water, leaving a few drops in the cup. Mix a 1-g. tube of hypochlorite into a paste with the few drops of water. Fill the cup to within 1 in. of the top (500 c.c.) and mix by pouring into another cup and back. This solution should contain 0.3 g. of available chlorine.

(2) Rinse four canteen cups with the water to be tested and fill to within 1 in. of the top. With a pipette or hypodermic syringe add 0.2 c.c. of the hypochlorite solution to the first cup of water; 0.4 c.c. to the second; 0.6 c.c. to the third; and 0.8 c.c. to the fourth. Mix the solution with the water in each cup by pouring into another cup and back and allow them to stand 30 min. (15 min. if time is important).

(3) Test each cup by adding 1 c.c. of the orthotolidin solution. The cup that contains the smallest amount of hypochlorite solution capable of giving an orange color contains the amount of chlorine necessary to sterilize the water.

Water Sterilizing Bag. The water sterilizing bag (or Lyster bag) when filled to the white mark contains 36 gal. or 288 pt. If, as in the example above, 0.4 c.c. of the hypochlorite was sufficient to sterilize 1 pt., 115 c.c. of the same solution will be sufficient to sterilize the contents of the bag. In practice it is safer to use twice this amount so that 230 c.c. of the hypochlorite solution would be added. In this case half of the prepared solution 250 c.c. would be added to one bag and the 500 c.c. (1 g. of hypochlorite) would be sufficient for two bags of water. Ordinarily 1 tube containing 1 g. of hypochlorite is added to a bag of water, dissolving it first in a cup. The tube should preferably be broken under water, working the powder into solution and then adding to the sterilizing bag. Another method of breaking the tube is to mark with a file, wrap in paper, crimp the ends and break the tube in the paper. Additional hypochlorite must be added when the tests show the necessity therefore and the water should stand for 30 min. before being used. In some cases two or even ten tubes may be required for one bag.

The orthotolidin is available in ampules and can be used for testing the sterilizing bag as follows: If one ampule is broken into a canteen cup of treated water drawn from the bag and it is stirred, the intensity of the color will determine whether or not sufficient hypochlorite has been added. If

the color is a lemon yellow, the amount is insufficient and more tubes of hypochlorite should be used until the test shows a distinct orange or orange-red color. (The color normally requires about one minute to appear). As the hypochlorite is more efficient in clear waters, a filter cloth is provided by which considerable turbidity can be removed.

Should sterilizing bags not be available galvanized iron cans can be used or the water in the water cart can be treated by adding the required proportions of a hypochlorite. In emergencies a tube can be broken in a cup-full of water and the resulting solution poured into a canteen which is filled with water and shaken. Other canteens can then be sterilized by adding one canteen cap-full (8 c.c.) to each canteen of water, shaking and allowing to stand 20 to 30 min. If the strong solution is to be kept for any length of time it must be in glass as this strength will attack the metal.

Sterilization for Detached Troops. Sterilization of water for detached troops may be accomplished by boiling *actively* for 10 min. or more. Boiled water has a flat taste, unless aërated, but may be made palatable by making weak tea. Muddy water may be clarified by straining through a filter cloth or blanket.

By adding 10 c.c. (2½ teaspoonfuls) of a standard 7 per cent. tincture of iodine a sterilizing bag of raw river water may be rendered safe in 30 min. This is approximately equivalent to two drops to the quart of water in the canteen. The Medical Department carries "swabs" containing 1½ c.c. of 3½ per cent. tincture of iodine. Twenty c.c. of the swab solution is equivalent to 10 c.c. of the standard tincture. Tubes of "Iodine-Potassium Iodide" in dry form, containing about 1 g. (15 gr.) of iodine and about 1.5 g. (22.5 gr.) of potassium iodide, are also available in the Medical Department for making 50 c.c. of a 2 per cent. solution. Thirty-five c.c. of this solution is equivalent to 10 c.c. of the standard tincture for sterilizing. The efficiency of these solutions has been demonstrated but they should not be used if hypochlorite is available. The excess of iodine may be removed, as with the hypochlorite, by adding 1 g. of sodium thiosulphate to the sterilizing bag.

If potassium permanganate ($KMnO_4$) is added to water it gives a purple color and if used in sufficient quantity so that the color persists 10 min. it causes effective sterilization — partly by oxidation, partly by precipitation of a manganese hydrate. A solution of alum and potassium permanganate may be useful for purifying and clarifying small local supplies. Potassium permanganate is efficacious against cholera but is less efficient where the water contains typhoid bacteria and the hypochlorite should be used when it is available.

Halazone has been found to be effective in sterilizing small quantities of water for individual use. It is reasonably stable and the tests of Dakin and Durham show that 3 p.p.m. (1.5 p.p.m. available chlorine) will sterilize heavily polluted waters in 30 min. and remove pathogenic organisms. It

can be obtained in tablets containing $\frac{1}{16}$ gr. (.004 g.). One tablet is sufficient for 1 liter or quart of water.

Sterilization of Well Water. The amount of calcium hypochlorite solution required can be computed by the orthotolidin test and added to all containers taken from the well. Or the hypochlorite solution may be added to the well itself until the tests show a sufficient amount of free chlorine. Frequent tests must be made to determine when additional hypochlorite is needed.

Wells can also be treated by placing 4 g. potassium permanganate and 10 c.c. hydrochloric acid in the well and leaving 24 hours. If the water has lost its pink color, more must be added. Pump until well is clear. The action is probably weakly germicidal except against cholera.

In one instance a well in France which had been badly fouled by the enemy with excrement was cleaned carefully and about three lbs. of hypo-

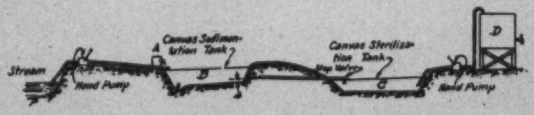

FIG. 15. — IMPROVISED PURIFICATION PLANT.

chlorite added. This was left some hours and then the well pumped vigorously for some time and the treatment repeated. After four days the water was found to be of good quality.

Small Purification Plants. Small purification plants can be improvised as shown in Fig. 15. Alum solution of the required strength is made up in tank *A* and added to the water as it is pumped into tank *B* from the stream so as to be thoroughly mixed. Let stand for about 8 hours. Draw off clear water into tank *C*, and add the required amount of hypochlorite solution, mixing thoroughly. After standing 30 min. the water can be pumped to the storage tank *D*. Tests for free chlorine should be applied. The outlet pipe of tank *B* should be 4 in. above the bottom of the tank. There should be a depression at one end, *S*, to act as a sump for cleaning and the tank should slope slightly in that direction. Sludge can be removed with a hand pump and a little water. The standard canvas basin can be used for all tanks and connections made with hose or pipe. If the water requirements are greater than 4 000 gal. in 8 hours, additional sedimentation tanks can be used.

Mobile Purification Unit. The entire equipment of this unit is mounted on a 3½-ton Class B truck and consists of a modified truck body; a single stage, 2-in. double-suction, horizontal centrifugal pump, directly coupled to a 4-cylinder gasoline engine of 20 to 25 h.p.; a 42-in. rapid sand

pressure filter, 5 ft. high, with a hand agitator; a five-way control valve; a combination direct dry-feed and solution-feed chlorinator; an alum pot; a 12-gal. soda-ash tank with appropriate feeds; a 32-gal. contact tank; a venturi meter; and a simple laboratory for making acidity, alkalinity, free chlorine, color, and turbidity tests.

The water is drawn in through the suction line by the centrifugal pump and forced to the five-way valve, which can be set to normal filtering, filter to waste, washing filter, by-passing the filter (i. e., from pump to contact tank), or closed.

Chlorine is fed into the suction line and is thoroughly mixed with the water while passing through the pump and filter. Sufficient chlorine (as

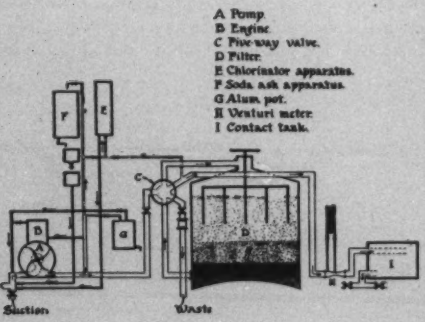

FIG. 16. — DIAGRAM PIPING SYSTEM OF MOBILE PURIFICATION UNIT.

determined by tests with orthotolidin) is applied to leave a minimum of 0.5 p.p.m. of free chlorine in the effluent. The chlorine is supplied in steel cylinders containing 1.1 cu. ft. or approximately 100 lbs. of the liquified gas. A solution of alum is also fed into the suction line and reacts with the alkali in the water to form a flocculent precipitate which is deposited in a layer on the top of the sand in the filter. If the water is normally acid, neutral, or has insufficient alkalinity this precipitate does not form and it is necessary to add a certain amount of alkali (2 per cent. or 3 per cent. sodium carbonate) by means of the soda ash system, feeding likewise into the pump suction. Sufficient alum is used to remove the turbidity and leave a residual alkalinity of 10 p.p.m. in the effluent. In general one grain of alum per gallon reduces the alkalinity by 5 p.p.m. The correct amount is determined by the difference in alkalinity between the raw and filtered water. If ferrous iron is present it will be precipitated after filtration as a reddish ferric iron. The addition of hydrated lime through the alkalinity device changes the ferrous to ferric iron which is then removed by the filter.

After passing through the filter the water normally goes to the contact tank where it is retained for a brief time to permit the chemical action of the chlorine, and to furnish a small reservoir for the laboratory water supply. The discharge lines lead from the contact tank at both sides of the truck.

The pump has a rated capacity of 100 g.p.m. against a 75-ft. head when operating at 1 150 r.p.m. It may be operated as a simple pumping unit, as a pumping and chlorinating unit or as a pumping and filter unit with or without chlorination. The capacities under different conditions are given in Sect. I on equipment of the Water Supply Battalion.

FIG. 17. — MOBILE PURIFICATION TRUCK.

CONVENIENT DATA

1 gram	=	15.43 grains
	=	Weight of 1 cubic centimeter of water
1 kilogram	=	2.20 pounds av.
1 grain per gallon	=	17.1 parts per million
1 part per million	=	.0583 grains per gallon
1 pound (av.)	=	7 000 grains = 0.4536 kilogram
grains per gallon/7	=	Pounds per 1 000 gallons
1 Imperial gallon	=	1.20 gallons (U. S.)
1 gallon (U. S.)	=	231 cubic inches
	=	.1337 cubic feet
	=	3.785 litres
	=	8.345 pounds (av.) of water
1 atmosphere	=	29.92 inches mercury
	=	33.90 feet of water
	=	14.7 pounds per square inch
	=	760 millimeters mercury
1 gallon per minute	=	0.002228 cubic feet per second
1 cubic foot	=	62.43 pounds water (average)
	=	7.480 gallons (U. S.)
	=	28.32 litres
1 cubic foot per second	=	448.8 gallons per minute
	=	0.0864 million cubic feet per day
	=	646 317 gallons per day
1 000 000 gallons per day	=	1.547 cubic feet per second
	=	694.4 gallons per minute
1 barrel (oil)	=	42 gallons (U. S.)
1 pound per square inch	=	2.31 feet water
1 foot water	=	0.434 pounds per square inch
1 inch on 1 square mile	=	2.323 million cubic feet
1 foot on 1 square mile	=	27.88 million cubic feet
1 K. W.	=	1.34 H.P.
1 H.P.	=	550 foot pounds per second = 0.746 K.W.
	=	3 953 foot gallons per minute
	=	5 694 000 foot gallons per day
1 sterilizing bag	=	36 gallons (to the white mark)
1 water cart	=	110 gallons
1 tank truck	=	500 gallons
1 light railway tank car	=	2 000 gallons
1 standard railway tank car	=	8 000 to 10 000 gallons
1 canvas water basin (20 x 20)	=	4 000 gallons (approx.)
1 canteen	=	1 quart (approx.)
	=	950 cubic centimeters (approx.)
1 canteen cup	=	700 cubic centimeters (approx.)
1 canteen cap	=	8 cubic centimeters (approx.)
	=	2 teaspoonfuls
Area of circle	=	$\pi r^2 = \frac{1}{4}\ \pi d^2$
	=	$0.7854\ d^2$
π	=	3.1416
g (average)	=	32.2 feet per second per second
v (theoretical velocity)	=	$\sqrt{2gh}$
	=	$8.02\sqrt{h}$
h (velocity head)	=	$\frac{v^2}{2g}$
	=	$0.0155\ v^2$

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Clean pipe lines deliver more water and give better fire protection at less cost than do corroded mains.
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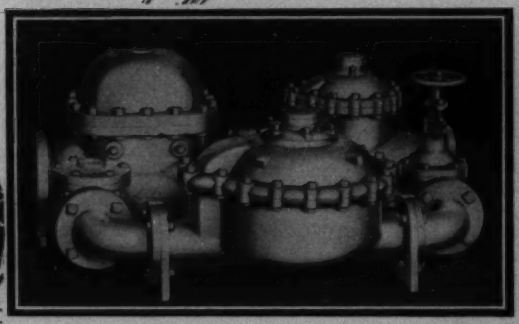
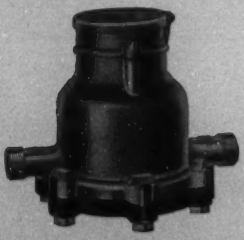
BILLIONS are Staked *on the* Dependability *of this* Meter



THE Hersey Detector Meter, for more than twenty years, has been accepted by every stock and mutual insurance company in the United States and over 800 water departments and water companies with absolutely no reservations.

The safety of billions of dollars of insured property value is staked on the dependability of this meter. It has never failed. It meets every requirement of a fire service meter. We shall be glad to send a catalog on request.

Hersey Manufacturing Company, South Boston, Mass.



There is only one internally balanced disc water meter. That is the Hersey.

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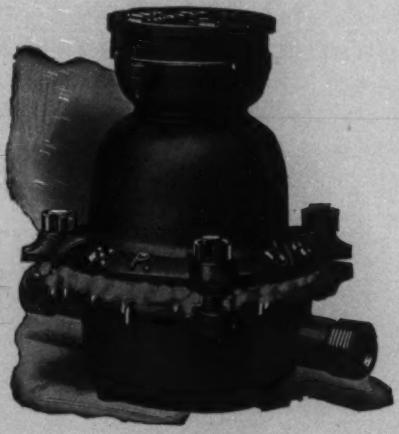

FROZEN!—but not damaged

Here is an actual photograph of a LAMBERT Frost-proof Meter which has been frozen to an extent that would put the ordinary meter completely out of commission.

This is made possible by a patented, non-corrosive yielding bolt device which allows the upper and lower casing, disc chamber and gear train to part without damaging the meter in any way. Five minutes' labor the only repair cost.

The expense and annoyance from frozen water meters can be eliminated for all time through the installation of the LAMBERT Frost-proof.

It has been proved that the LAMBERT is the easiest water meter to take apart and put together again as well as the simplest, most reliable and accurate.

If you are interested in other types of meters, we make one for every requirement.

THOMSON METER CORPORATION

SALES OFFICE: 50 EAST 42nd STREET, NEW YORK CITY, N. Y.

LAMBERT FROST-PROOF METERS

Every pioneering improvement that has eventually influenced the entire water meter industry has always been foreshadowed first in Neptune TRIDENT Meters

NEPTUNE METER COMPANY
THOMSON METER CORPORATION
50 EAST 42ND STREET NEW YORK CITY
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PIONEERS IN METER PROGRESS

ANNOUNCEMENT

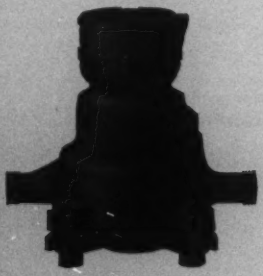
Pittsburgh Water Meters will hereafter be manufactured and sold by the Pittsburgh Equitable Meter Company.

The Pittsburgh Equitable Meter Company will have very much larger facilities and, therefore, the trade is assured that the same products will be available with no change, except in the benefits accruing from the increase in both the organization and plant facilities.

Water Meter stocks will be carried in a number of new branches and additional offices will soon be announced, which will enable us to keep in closer touch with the trade.

PITTSBURGH EQUITABLE METER CO.

WATER METERS FOR EVERY PURPOSE
DOMESTIC AND INDUSTRIAL



ARCTIC

A frost-bottom meter, especially designed for cold sections of the country.

TROPIC

An all bronze Water Meter, with connection spuds attached to the lower case. Particularly designed for warm sections of the country.

PITTSBURGH EQUITABLE METER CO.
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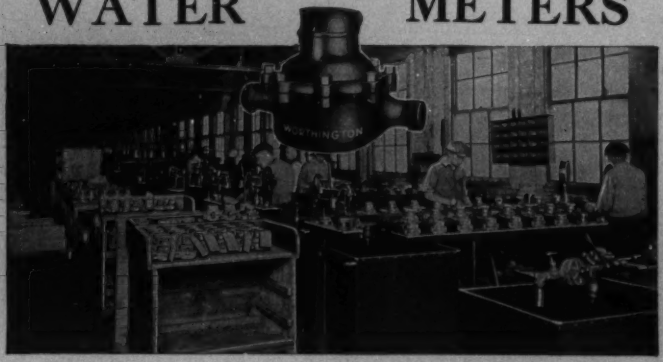
WORTHINGTON

WATER METERS



View of Small-Meter Testing Department, Worthington Works, Harrison, N. J.

THERE is a Worthington Water Meter for every requirement from the measuring of small customer flows to the measuring of flows of 10,000,000 gallons per 24-hours.

Types of Worthington Meters

Disk Meters — furnished with open train or enclosed oil train. Smaller sizes can be fitted with frost protector.

Turbine Velocity Meters

Compound Meters

Hot-water Meters for boiler-feed lines.

Oil Meters for hot oil and for cold oil.

Stocks of meters are carried in our branch houses in all parts of the country to insure prompt service.

Pumps and Pumping Engines **Compressors** **Condensers**
Oil and Gas Engines **Feedwater Heaters** **Water and Oil Meters**

WORTHINGTON PUMP AND MACHINERY CORPORATION
115 BROADWAY, NEW YORK CITY BRANCH OFFICES IN 24 CITIES

The History of VENTURI No. 4

Over 100 years ago Venturi announced the basic law. In Herschel's hands Venturi's converging pipe became, in 1887, a master meter.

The Principle of The Venturi Meter

When water (or other liquid) flows through a pipe containing a contraction like Fig. 1, the pressure at the throat B is less than at the inlet A, due to the increased velocity at B. If the pipe is properly proportioned this loss of pressure is almost entirely regained at the outlet C, due, in turn, to the gradual decrease of velocity after the water passes the throat. These facts can be easily demonstrated with pressure gauges at A, B, and C. Practically the same amount of water, therefore, will be delivered through such a tube as through an equal length of straight pipe of the same inlet and outlet diameter.

Herschel proved that a very remarkable and definite relation exists between the difference in pressure (the "Venturi head") between A and B and the velocity at C (Bulletin 205 gives the exact formula).

Builders Iron Foundry engineers completed the work of Venturi and Herschel by the invention of a practical registering device having the readings controlled by the Venturi head.

Today, throughout the entire world, the Venturi Meter on main pipe lines is showing the total water consumption of towns, cities, and districts; checking the performance of pumps; recording continuously the hourly variation in day and night rates of consumption; controlling the rate of filtration; measuring the flow of sewage; furnishing reliable data for future extensions to water-works and sewage disposal systems; revealing unsuspected pipe line breaks, etc.

In what kind of service are you interested? Helpful bulletins are available.

BUILDERS IRON FOUNDRY,
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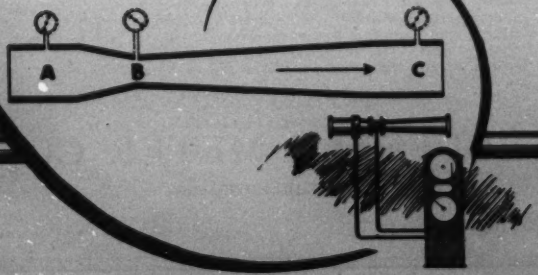
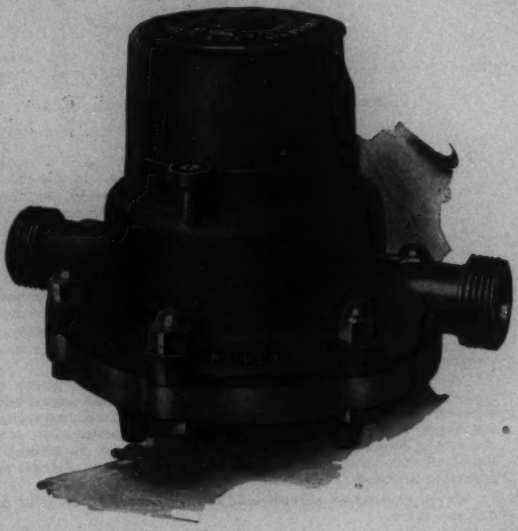


AMERICAN AND NIAGARA WATER METERS



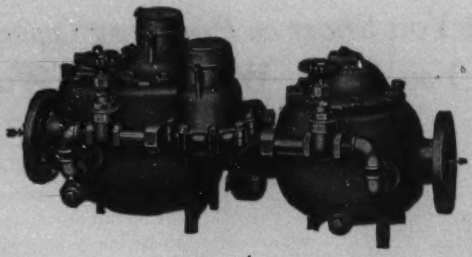
American and Niagara meters are made in solid casing types and frost bottom types. The illustration above shows a $^5/_8$" x $^1/_2$" meter of the frost bottom type. Those meters having bronze outside casings are known as Americans and those having galvanized cast-iron outside casings are Niagaras. The works in all the different casings are of one best model and interchangeable. The registers may be either round reading or straight reading and may indicate cubic feet, U. S. gallons, imperial gallons or litres. All Niagara and American meters are tested and adjusted according to the requirements of the Standard Specifications for water meters adopted by the New England Water Works Association and the American Water Works Association.

Write for large catalog and prices.

BUFFALO METER CO.

ESTABLISHED 1892

2896 Main Street **BUFFALO, N. Y.**



The New Nilo

The new improved **Nilo Compound Meter** now comes equipped with a bronze body. This is a valuable addition to meter service for it eliminates the danger of corrosion and filling up due to the collecting of corrosive matter. Bronze being stronger than iron the gross weight of the meter is less, making it easier to transport, handle and install.

It also has two gate valves which allow the removal of the by-pass meter for cleaning or repairing without shutting off the line.

The controlling valve mechanism of the new **Nilo Compound Meter** is self contained and easily detached from the main body casings.

These three improvements make the **Nilo,** a long standing favorite, the unrivaled leader in its field.

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Incorporated 1868

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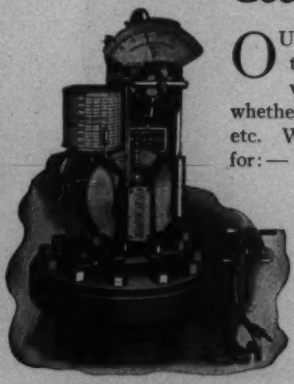
Is Your Pressure Low?
Are You Short on Pumping Capacity?
Do You Know Where Your Water Goes?



OUR Engineering Department will tell you how to determine your water distribution, how to find out whether or not new mains are required, etc. We can supply you with the means for: —

1. Checking up pump performance and determining slippage due to leaky plungers, defective valves, short stroking or other causes,
2. Measuring delivery of centrifugal pumps and figuring whether or not the station is up to efficiency,
3. Distributing proportionately the cost of water supplied to several districts,
4. Checking up the performance of filter beds,
5. Detecting waste or pipe leakage,
6. Recording daily amounts of sewage handled and planning future extensions, etc., etc.

THE SIMPLEX METER

VENTURI, PITOT TUBE OR ORIFICE TYPES

THE importance of exact measurements by means of a Simplex Meter cannot be over emphasized. Mr. Jeffries, Chairman of the West Chester, Pa. Water Works Committee, was able, by checking the performance of his pumping engine with a Simplex Meter, to discover that due to the imperfection and wear in the valves the slippage amounted to 300,000 gallons of water per day. This represented a daily loss of $30.00, or in other words a daily saving of $30.00, or $900.00 per month, when the valves were put in order. The Simplex Meter thus paid for itself in a month's time.

Frequent repeat orders from satisfied customers who formerly used other meters are the best evidence of merit of the Simplex Meter.

We have had many years' experience in solving water flow problems involving all sorts of conditions, and we are at all times prepared to submit general layouts involving cost and capacity, and to make explicit and complete recommendations. Write for Bulletin N26.

SIMPLEX VALVE AND METER COMPANY

Manufacturers of Meters for Water, Sewage, and Other Liquids, Rate Controllers, Automatic Air Valves, Regulating Valves, and Hydraulic Apparatus of Special Design.

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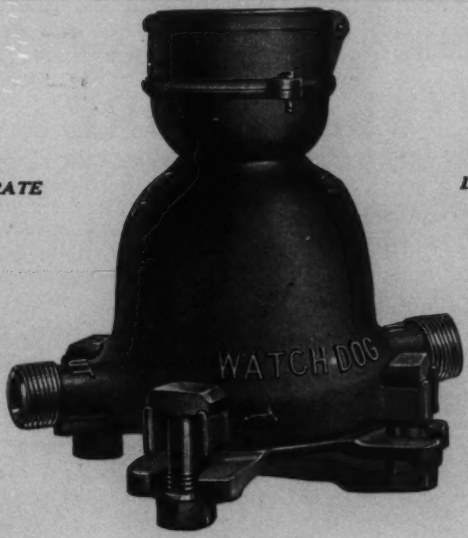
"WATCH DOG" WATER METERS

ACCURATE *DURABLE*



DISC, CURRENT AND COMPOUND TYPES

Inquiries Solicited

GAMON METER COMPANY

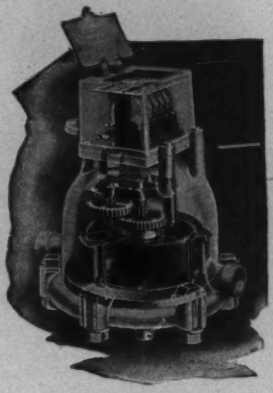
NEWARK NEW JERSEY

METERS

Water Departments wishing to make the most out of their supply, to earn the highest possible revenue, and to satisfy their customers, are invited to investigate

The EMPIRE

OSCILLATING PISTON METER



Sizes from 5/8″ to 6″

Accuracy, lasting qualities, and economy of upkeep are the three essentials of satisfactory meters. The EMPIRE offers some remarkable records on these three points. Ask us.

Fully descriptive EMPIRE circular gladly sent on request.

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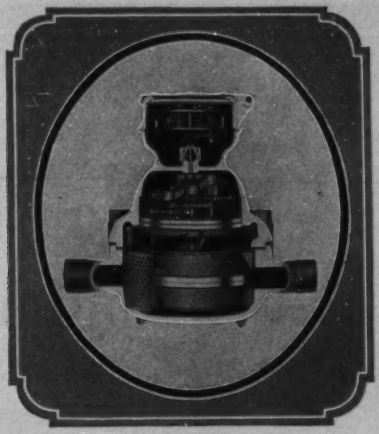


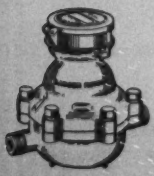
Protection!

It is not at all surprising that the Badger Meter with oil-enclosed gear train out-lasts ordinary meters. Particularly where electrolytic or alkaline action is especially severe. Corrosion cannot attack the working parts.

The entire intermediate gear train of the Badger is enclosed in a separate, oil-tight compartment filled with a special non-congealing graphite oil. The gears are constantly and thoroughly lubricated — ***protected!***

Think of what this means in the life of your meters — in accurate registration — in revenue. Let the Badger prove itself on your lines. Write for detailed information.

Badger Meter Manufacturing Co.
Milwaukee, Wis.



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No "beef" – all brawn

To speed the drilling job and make it possible to do much of the work with one man, all excess metal was removed from the Mueller "C" Drilling Machine. It has the vitality and strength that comes with scientific lightness and correct design. During the past eight years its better service has secured it increasing favor in the water-works field.

Mueller Machine "C" makes lateral and branch connections from 2″ to 8″ inclusive in pipe from 4″ to 48″. All working parts run in heavy grease in a dustproof housing. Automatic feed prevents overfeeding the drill. One main shaft serves for cuts of all sizes and the various sized drills are easily and quickly fitted to this shaft. Comes in an iron bound box with compartments for the calking tools, wrenches and 2″, 3″, 4″, 6″ and 8″ shell drills and adapters which are included with this machine.

For smaller cuts, use the Mueller "B" Drilling Machine, made on the same general plan as the husky "C."

These machines make a good, clean cut and do it *quickly*. The men and the management like them. Write for all details.

MUELLER CO. (Established 1857), Decatur, Illinois

Branches: New York, San Francisco, Los Angeles
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MUELLER

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ATTENTION
WATER WORKS
OF NEW ENGLAND

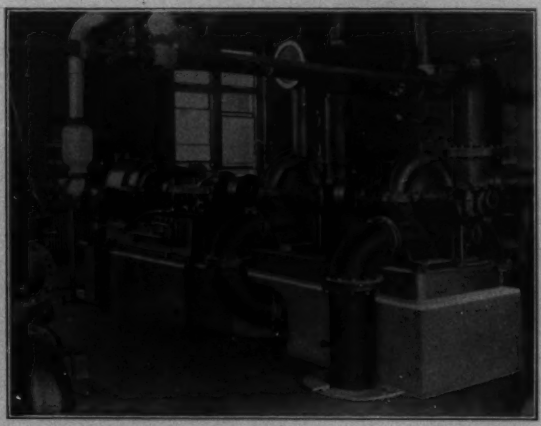
A few reasons why we solicit your inquiries on Water-Works Pumping Equipment:

First. — We make a specialty of furnishing Complete Water-Works Pumping Units of all types.

Second. — Total responsibility of installation is assumed by us.

Third. — We relieve the purchaser of every detail and turn the complete unit over to him under actual operation and with guarantee.

Fourth. — Every unit installed to date has exceeded its guarantee and has been completely accepted.



Turbine-driven Pump at the Arlington Station of the Metropolitan Water Works, Boston, Mass.

F. A. Mazzur Co., Inc.

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STARKWEATHER & BROADHURST, Inc.

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"One Contract and Responsibility"

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HORIZONTAL AND VERTICAL DESIGNS
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Some Recent New England Installations

Town of Framingham.
Four Motor Units.

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Three Motor Units.

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Eight Motor Units.

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One Motor Unit.

City of Woburn.
One Turbine Unit.

City of Springfield.
Five Motor Units.

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Three Motor Units.

Town of Jaffrey, N. H.
One Motor Unit.

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Town of Amesbury.
Two Motor Units.

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Pumping Plant Contractors

CENTRIFUGAL, POWER, STEAM PUMPS

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Power Plant Equipment
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For new pumping equipment guaranteed by people who will make good, phone, wire or write the above.
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WE announce our appointment as Sales Representatives of DAYTON-DOWD COMPANY, of Quincy, Ill., Manufacturers of Centrifugal Pumping Machinery. After exhaustive investigation, we present this line of equipment to the Trade in New England as being of the highest grade and thoroughly modern in design and manufacture.

We are prepared to furnish DAYTON-DOWD pumps in all sizes and for all classes of service, in steam, motor, gasoline and belt drive types, and solicit your inquiries, assuring you of our best efforts in your sales and service requirements, and of our appreciation of your continued confidence and patronage.

POWER EQUIPMENT CO.

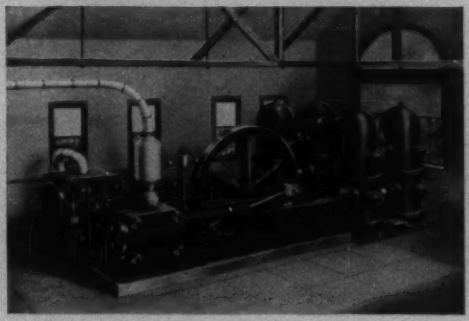
131 State Street, Boston, Mass.

MURRAY IRON WORKS CO.

(INCORPORATED 1870)

BURLINGTON, IOWA, U. S. A.

Builders of High Duty Pumping Engines



Murray High Duty Crank and Fly Wheel Pumping Engine, Opposed Type

Engineers, Iron Founders, Boiler Makers

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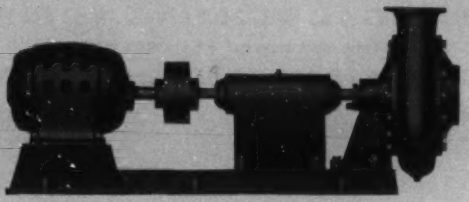
Water-Tube, Fire-Tube and Internal-Furnace Boilers

Builders of Complete Power Plants

PLEASE SEND US YOUR SPECIFICATIONS AND CALLS FOR BIDS



Fairbanks-Morse Horizontal Trash Pump direct-connected to Fairbanks-Morse Ball-Bearing Motor

Now a great advance in sewage pumping

For the first time a pump has been designed that will handle fluids containing the fibrous and stringy matter found in sewage — without clogging, without preliminary screening, and without the excessive power consumption that characterizes the less satisfactory open impeller type of pump.

The secret of this pump's success lies in the design of the simple two-blade impeller. The blades of the impeller have well-rounded entering ends and are well filleted with the shrouds or sides. Thus a rag or other trash does not find sharp projections on which to catch and cause clogging. Since the impeller is the enclosed type, foreign matter, in passing through, does not come into contact with stationary side plates, but is promptly discharged through one of the large ports into the pump case. In this way power is conserved and efficiency increased.

This pump was designed by Mr. A. B. Wood who has been serving the city of New Orleans and other municipalities in the capacity of consulting engineer. It was originated by Mr. Wood to cope with the very unusual sewage problems found in New Orleans and met with immediate success.

Fairbanks-Morse Trash Pumps are made in two types, horizontal and vertical. They are ruggedly built to cope with severe service and at the same time they possess such refinements as ball bearings, smoothed fluid passages, and other marks of quality construction.

Ask for bulletins giving complete details.

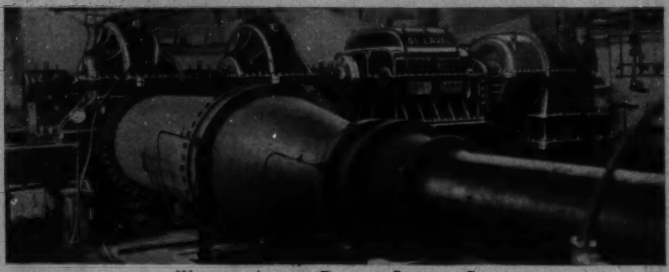
FAIRBANKS, MORSE & CO., Chicago

28 branches in principal cities at your service.

FAIRBANKS-MORSE

PUMPS · DIESEL ENGINES · MOTORS

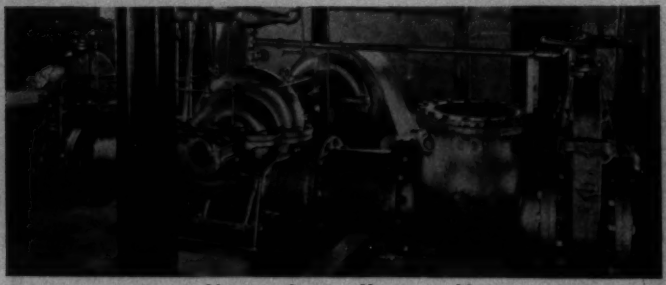
DE LAVAL
CENTRIFUGAL PUMPING EQUIPMENT
is the accepted standard for
MUNICIPAL WATER WORKS



WESTERN AVENUE PUMPING STATION, CHICAGO.

The largest Municipal steam turbine driven centrifugal pumping unit in the world delivering 75 million gallons per day against 150 feet head.
City of Chicago has fourteen large DE LAVAL pumping units.

TYPICAL NEW ENGLAND INSTALLATION



MILLVALE STATION, HAVERHILL, MASS.

New 7 million DE LAVAL motor-driven pump including the furnishing and erection of transformers and switchboard equipment. On test after installation this pump delivered water at rate of 7,800,000 gallons per day. Another DE LAVAL unit is on order for Kenoza Station, Haverhill.
Recent DE LAVAL municipal water works contracts include New England installations at Canton, Mass., and Millis, Mass.

Ask for De Laval Publication.

TURBINE EQUIPMENT CO. of NEW ENGLAND
CHAMBER OF COMMERCE BUILDING
80 Federal St., Boston
NEW ENGLAND REPRESENTATIVE FOR
DE LAVAL STEAM TURBINE COMPANY
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All Well Waters —Should Be Chlorinated

The Elizabethtown Water Company, Elizabeth, New Jersey uses the new W & T Chlorinator, type M S P, to sterilize every drop of well water.

PUBLIC HEALTH ENGINEERS are rapidly dissipating the old-fashioned but popular idea that well waters are pure and safe to drink just because they are well waters and come from under-ground sources.

They know that well waters are liable to pollution—that a fissure in the rock or a break in the well casing often permits disease ladened contamination to enter the supposedly pure water—particularly in times of flood.

They know that hundreds of Typhoid Fever Epidemics have been caused by well waters.—They know that the three outstanding typhoid epidemics in recent history—Salem, Ohio — Lansing, Michigan — Santa Anna, California—were all caused by polluted, *unchlorinated* well water.

That is why there is a marked tendency toward the chlorination of all well waters—because a properly chlorinated water cannot cause disease—because chlorination will not change the physical or chemical characteristics of the water in any way — because chlorination costing but one cent per capita per year is the cheapest public health insurance.

"The Only Safe Water is a Sterilized Water"

WALLACE & TIERNAN

COMPANY, INCORPORATED

Manufacturers of Chlorine Control Apparatus

NEWARK, NEW JERSEY

NEW YORK CHICAGO KNOXVILLE SAN FRANCISCO MINNEAPOLIS PITTSBURGH DALLAS
KANSAS CITY LOS ANGELES SEATTLE ST. LOUIS BUFFALO HARRISBURGH INDIANAPOLIS
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Founded 1853 Incorporated 1863

MERRIMAC CHEMICAL 1863 COMPANY

FILTER ALUM

Aluminum Sulphate

A basic, uniform product which has been used successfully by the leading water filtration plants in New England for many years.

Our location and shipping facilities place us in a position to offer insurpassable service and make us the logical source of supply for all filter plants in New England.

The aid and advice of our technical staff has often proved of great value to our customers. It is always at their service.

MERRIMAC CHEMICAL CO.

148 STATE ST., BOSTON, MASS.

Works:

EVERETT, MASS. WOBURN, MASS.

PRECALKED JOINT PIPE

Can be laid three times as fast as ordinary pipe, for half the labor. B. & S. type. Sand cast. Precalked Fittings also.

McWane Cast Iron Pipe Company

Eastern Office
819 Bankers Trust Bldg.
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New England Representatives:

FRED A. HOUDLETTE & SON
40 Central Street, Boston
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BUILDERS IRON FOUNDRY
Providence, R. I.
R. I., Conn., Vt., Western Mass.

GRIP PIPE FITTINGS

Connect without threading

As an Emergency Pipe Clamp

Before

After

Makes Possible an Immediate Repair. Saves Both Time and Money

MANUFACTURED BY

WARE COUPLING & NIPPLE MFG. CO.

WARE, MASS., U. S. A.

Founded 1853 Incorporated 1863

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After

Makes Possible an Immediate Repair. Saves Both Time and Money

MANUFACTURED BY

WARE COUPLING & NIPPLE MFG. CO.

WARE, MASS., U. S. A.

40 Years Old—Still Serving!

In the life of a pipe line, forty years is a long time — particularly if it is spent underground, subject within and without to corrosive onslaughts.

The pipe that can stand it is the pipe for service lines. That genuine wrought iron pipe has the necessary endurance is clearly demonstrated by service records all over the country of which the above photograph is an interesting example.

Here is a two-foot section from a line laid in 1886 by the Atchison Water Co. It is still good. It was removed simply to admit a valve. The line as a whole is in its 41st year of constant, uninterrupted service.

For sixty years, Byers has made pipe from genuine wrought iron. Its quality today is no less than that which has already defied rust for two, even three generations. Such, surely, is the ideal pipe for service lines.

A. M. BYERS COMPANY

Established 1864 **Pittsburgh, Pa.**

BYERS PIPE

GENUINE WROUGHT IRON

W. B. Hubbard & Sons Co.

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PIERCE-PERRY CO.

SUCCESSORS TO
GEORGE E. GILCHRIST CO.

JOBBERS OF
Heating and Plumbing Supplies
Steel, Wrought Iron and Brass Pipe
Water Works Materials

DISTRIBUTORS OF
Hoffman Valves and Controlled Heat Equipment

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BOSTON PIPE & FITTINGS CO.

WHOLESALE JOBBERS

Byers Genuine Wrought Iron Pipe

National Pipe

COMPLETE LINE OF WATER WORKS SUPPLIES

273-279 CONGRESS ST., BOSTON

We Carry in BOSTON STOCK for Immediate Shipment
CAST IRON BELL AND SPIGOT
WATER PIPE AND FITTINGS
FLANGED PIPE in full and short lengths
WROUGHT PIPE
FRED A. HOUDLETTE & SON
(Incorporated)
40 Central Street, Boston, Mass.
Quotations furnished promptly for shipment from Foundry

CEMENT LINED SERVICE PIPE

With Specially Adapted
Lead-lined Fittings

Also Curb Cocks which eliminate Iron to Brass Corrosion both inside and out.

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Manufacturers of and Dealers in
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Byers' Wrought Iron Pipe
Service and Valve Boxes
Cast Iron Pipe and Fittings

12-18 Pittsburgh Street - - Boston, Mass.
Telephone, Liberty 1350

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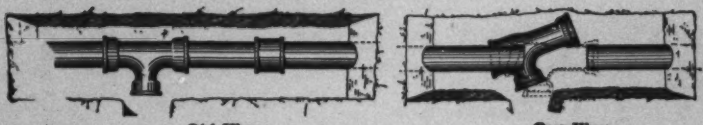
400 CHESTNUT STREET, PHILADELPHIA, PA.

Engineers, Iron Founders and Machinists

HYDRAULIC VALVES and MACHINERY

Cast Iron Pipe

CUTTING-IN TEES

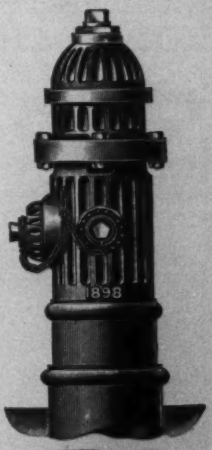


Old Way *Our Way*

Connections economically and easily made with one fitting. Saves sleeve, cuts, lead and unnecessary work and material.

"Reduced Specials"

Cost of fittings reduced from 25% to 50%. Full strength. Deep bells. Convenient to handle. Sold by the piece.



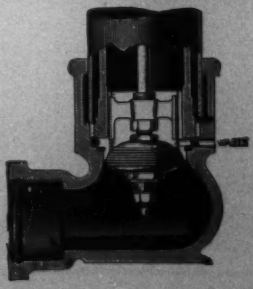
Mathews Fire Hydrants

A half century of use has established their reputation as being the most economical, durable and simple hydrant.

Number in use exceeds total of all other makes combined.

Gate Valves

R. D. WOOD & CO. STANDARD
DOUBLE DISK
ANTI-FRICTION
EXTRA WEIGHT, FINISH
AND MATERIAL



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VALVES-PIPE FITTINGS-FIRE HYDRANTS

50th Anniversary 1877-1927

Let's Go! CHICAGO 1927

A type for every water-works service

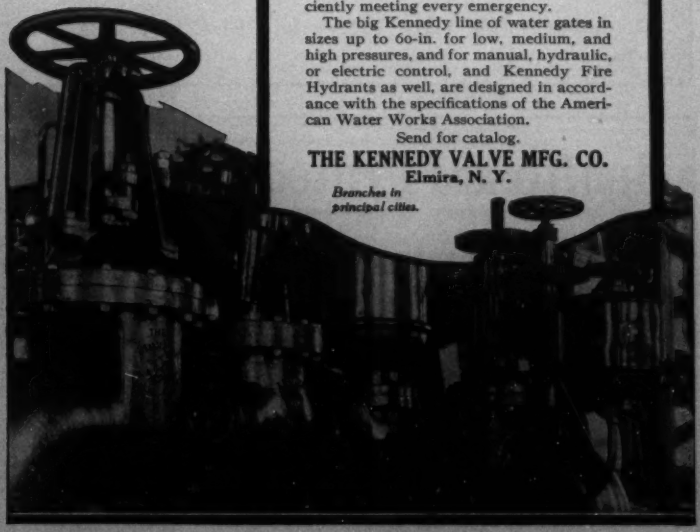
WATER-WORKS superintendents all over the country can testify to the uniformly dependable service and trouble-free operation of Kennedy equipment. On the water supply and fire protection systems of hundreds of municipalities, Kennedy Valves and Fire Hydrants are giving thorough satisfaction, promptly responding to every demand, and efficiently meeting every emergency.

The big Kennedy line of water gates in sizes up to 60-in. for low, medium, and high pressures, and for manual, hydraulic, or electric control, and Kennedy Fire Hydrants as well, are designed in accordance with the specifications of the American Water Works Association.

Send for catalog.

THE KENNEDY VALVE MFG. CO.
Elmira, N. Y.

Branches in principal cities.



Automatic Pressure Control Valves
Feed Water Filters
Portable Fire Hydrant Heads
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ROSS VALVE MFG. CO., INC. TROY, N. Y.
ESTABLISHED 1879

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Sluice Gates, Gate Valves and Fire Hydrants

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

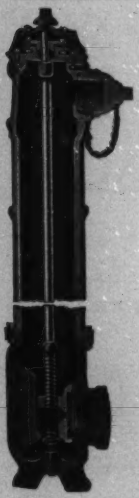
Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

50 Church Street New York City



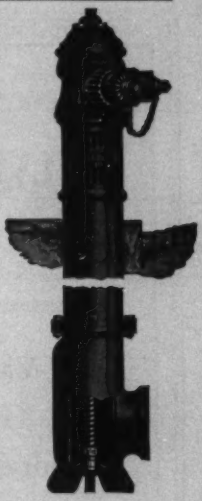
LUDLOW VALVE MFG. CO.

MANUFACTURERS OF

VALVES and FIRE HYDRANTS

This hydrant is anti-freezing, because when the drainage is good no water is left in it to freeze.

The drip is directly in the bottom of the hydrant and drains perfectly. It is protected by its valve, which never leaves its socket and cannot be clogged.



DOUBLE AND SINGLE GATE **VALVES,**

ALSO CHECK **VALVES,**

FOOT **VALVES.**

FIRE **HYDRANTS.**

YARD, WASH, AND FLUSH **HYDRANTS.**

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62 GOLD ST.	HARRISON BLDG.	1112 TREMONT BLDG.	1ST NAT. BANK BLDG.	THE ROOKERY	R. A. LONG BLDG.

The Knuckle Joint Principle in Genuine "Rensselaer" Improved "Corey" Fire Hydrants—Means Ease of Operation

BECAUSE this principle gives great power to open or close the gate just when it is needed, and speed in movement when power is unnecessary.

The first turn of the spindle, when the gate is open, moves the valve nearly two inches, after which the speed decreases and power throughout the knuckle joint increases, until at the time of closing the valve moves scarcely one-sixteenth of an inch at each turn of the spindle, eliminating danger from water hammer when closing hydrant.

The gate is closed very tight with slight application of power to the wrench by the operator. The drip valve in the Corey Fire Hydrant prevents freezing. No accident or damage to property can occur with this hydrant by flooding the streets where runaway teams or other accident breaks off or otherwise injures the hydrant standpipe, if hydrant was properly closed at time of accident.

It will be readily seen that the hydrant gate is held in position when shut by the four arms forming braces between the back of the hydrant and the seat, consequently the hydrant barrel can be broken completely off above the ground, but the valves remain tight.

Write for copy of our Hydrant Book No. 9.

CHARLES L. BROWN,

New England Sales Manager, Lock Box 2, Northboro, Mass.

RENSSELAER VALVE COMPANY

TROY, N. Y.

THE CHAPMAN VALVE MANUFACTURING COMPANY

Manufacturers of

Gate Valves Drip Valves

Gate Fire Hydrants

Corporation Cocks Curb Cocks

Anderson Couplings

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Type of Eddy Hydrant Popularly Used

More Than Sixty Years of Experience Goes Into All

EDDY

Hydrants and Valves

BUILT TO MEET EVERY EXACTING REQUIREMENT OF WATER-WORKS SERVICE

Practical water-works men instantly recognize the superior features of Eddy products. For instance, with the hydrant.

A damaged valve can be replaced in a few minutes — Water hammer is avoided by the valve closing against the pressure and the use of the cut-off under the valve, which gradually closes it —
Stems cannot be bent in closing the hydrant.
Nothing can lodge on the valve seat to prevent closing of the valve —
The Drip Rod can be removed without interfering with the hydrant in any manner —
The position of the stem of the hydrant indicates accurately the position of the valve —
Whatever can pass the valve opening will pass the standpipe —
No frost case necessary —
All of these points are explained thoroughly in our catalogue, which will pay you to study.

The Eddy Valve, Too

Has its distinctive and individual features. The double disk gates are free to adjust themselves in different positions every time the valve is closed, thereby keeping smooth and tight faces. And two bronze hooks on the ball loosely engage with the gates to prevent them from spreading at the top. The center bearing gates are forced to their seats with equal pressure at all points. There is a good deal more worth knowing about Eddy Valves. Further details will be sent for the asking.

Other Eddy Products

The Eddy line of water-works products also includes horizontal and vertical check valves, foot valves, hydraulically operated valves, indicator posts, etc.
All goods made by the Eddy Valve Company are manufactured exclusively at Waterford, New York.

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EDDY VALVE COMPANY

WATERFORD, N. Y., U. S. A.

EMAUS PIPE FOUNDRY,
DONALDSON IRON CO.,

MANUFACTURERS
...OF...

CAST IRON PIPE

...AND...

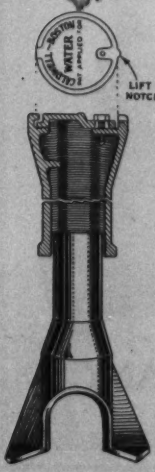
Special Castings for Water and Gas.
Also Flange Pipe, Street Castings,
Manhole Heads and Covers, etc.

J. G. EBERLEIN, President and Treasurer.
J. M. GILBERT, Secretary.

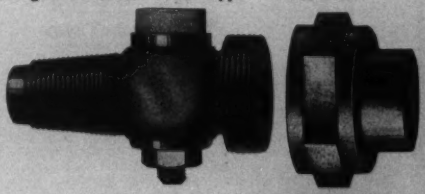
EMAUS,
LEHIGH COUNTY, PA.

The "BEST" Cast Iron Curb Box

Top section is interchangeable with the "Slide Type" Buffalo Box

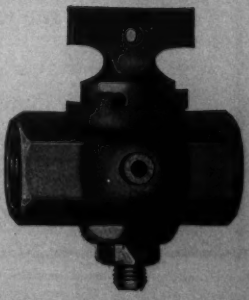


No change necessary in wrench or shut off keys



"CALDWELL" Water Works
Brass Goods, Curb and
Valve Boxes

None better and few as good



GEORGE A. CALDWELL CO.
Mattapan Square
BOSTON, MASS.

Atlantic City uses Cast Iron Pipe

in its water and gas supply lines and sewage disposal system

THESE illustrations demonstrate how well Cast Iron Pipe solves the problem of unusual installations.

The different lines run under sand, over salt marshes, on pontoons and across bridges.

Our engineering department will be glad to co-operate with you in the solution of any installation problem.

Write for U. S. Cast Iron Pipe handbook, which contains all necessary data on specifications.

United States Cast Iron Pipe and Foundry Company

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THE A. P. SMITH MANUFACTURING CO.

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Manufacturers of

Tapping Machines, Fire Hydrants, Water Gates,
Economic Lead Furnaces,
Corporation and Curb Cocks, Brass and Aluminum Castings.
Also General Supplies for Water and Gas Works.

Write for Catalogue.

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CAST IRON
WATER & GAS PIPES
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Special Castings, Fire Hydrants, Valves
General Foundry and Machine Work
WOOLWORTH BUILDING 233 BROADWAY
NEW YORK CITY

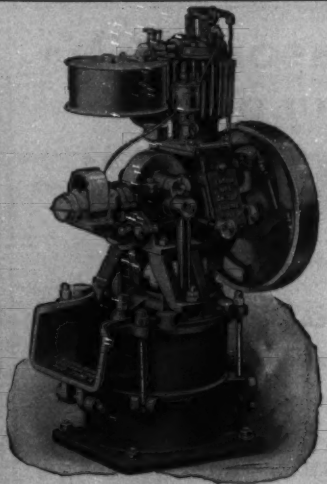
HIGHEST AWARD, GOLD MEDAL, ST. LOUIS EXPOSITION, 1904

Over 100 Water Departments
use
LEAD-LINED IRON and TIN-LINED PIPES
for their service connections

MANUFACTURED BY

Lead Lined Iron Pipe Company

Wakefield ——— Mass.



STYLE "S" ENGINE – STYLE "A" NO. 3 PUMP
Furnished on Hand Skid or 4-wheel Truck

"On Top" Trench Pump Unit

EDSON

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PUMP SPECIALTIES

Hand and Power Outfits

Try one of our Gasoline Two-Pump
EMERGENCY UNITS

Insist on GENUINE EDSON Pumps,
Suction Hose, Diaphragm
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New Catalogue on application

Edson Manufacturing Corp.
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CAST IRON PIPE

Bell and Spigot Flanged Pipe
Special Castings
Flexible Joint Pipe Cylinders

Water Gas Sewers Culverts

Works, Phillipsburg, N. J.
LARGE STOCK ENABLES US TO MAKE QUICK SHIPMENTS

Twelve Reasons Why

YOU SHOULD USE

Trade "LEADITE" Mark

Registered U. S. Patent Office

FOR

Jointing Water Mains

1. **DURABILITY.** Leadite joints increase in strength with age.
2. **NO CAULKING.** Leadite joints require no caulking, because the Leadite adheres to the pipe, making a water-tight bond.
3. **COMPARATIVE QUANTITIES.** One ton of Leadite is equivalent to four tons of lead.
4. **LABOR SAVING.** Saves caulking charges and digging of large bell-holes, and reduces the cost of trench pumping to the minimum.
5. **COST.** Its use saves 50 to 65 per cent. over lead, owing to the saving effected in material and labor.
6. **TOOLS.** As no caulking is required, fewer tools are needed.
7. **TRANSPORTATION.** Considerable freight charges are saved because Leadite is lighter than lead.
8. **HAULING.** Saves hauling expense on the work because you move only one fourth the weight of jointing material.
9. **FUEL.** Saves fuel because you melt only one ton of material instead of four, and not as much heat is required either.
10. **DELIVERY.** We can make prompt shipments.
11. **DAMAGE SUITS.** Claims for damages caused by joints blowing out are prevented because Leadite joints will not blow out under any pressure.
12. **USERS.** Progressive water works all over the country use Leadite.

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Land Title Building Philadelphia

P. E. KELLY, New England Representative

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Chadwick-Boston Lead Co.

800 Albany St., Boston

Agents for

The Celebrated "ULCO"

LEAD WOOL

(Every Atom Pure Lead)

For calking pipe joints under the most difficult conditions.

For overhead joints, or in wet places where the use of molten lead is not only impracticable but dangerous — **LEAD WOOL** may be used to advantage.

It makes an absolutely tight joint which will withstand the highest pressure, yet be sufficiently elastic to allow considerable sagging or settling of the pipe without danger of a leak.

As compared with the poured joint, in this respect, the superiority of **LEAD WOOL** is apparent.

Manufacturers of

Lead Pipe, Tin Lined Lead Pipe, Pure Block-Tin Pipe, Solder, White Lead and Red Lead.

HIGHEST QUALITY SOFT BRANDS

PIG LEAD

TEN CENTS PER POUND PRICE TEN CENTS PER POUND PRICE TEN CENTS PER POUND TEN CENTS

Join Your Water Mains

WITH

LEAD-HYDRO-TITE

TRADEMARK

AND CUT YOUR EXPENSES

50% FIRST COST

50% SMALLER BELL HOLES

75% HANDLING

100% CALKING

OUR PROPOSAL

That the prospective users purchase a trial lot of 1 to 5 bags, and that this be used under the direction and according to the instructions of our representative.

If, after a trial, the purchaser is not satisfied with the material, any surplus not used to be returned to the Hydraulic Development Company, and no charge to be made for any of the Hydro-Tite furnished.

Owned, Manufactured and Sold by New Englanders

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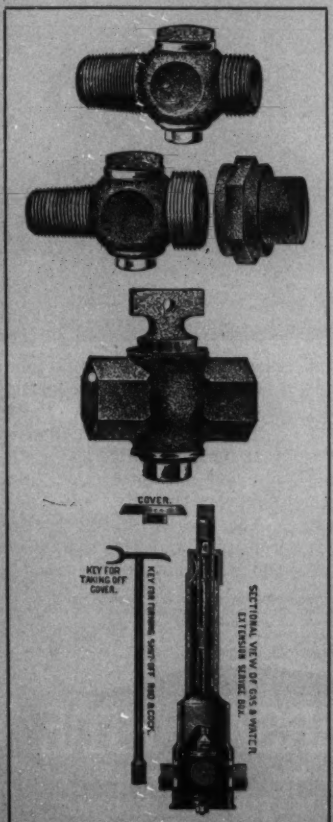
TEN CENTS PER POUND PRICE TEN CENTS PER POUND PRICE TEN CENTS PER POUND TEN CENTS

"The Goods That Please"



Corporation and Curb Cocks

We have them to meet every requirement

ORIGINAL

"Hays-Erie"

Extension Service Boxes of proven advantages

Let us send at our risk, on 30 days' trial, a

Payne's Patent Tapping Machine

which is recognized to be the most easily operated owing to the few working parts.

Hays Mfg. Co., ERIE PENNSYLVANIA

Established 1869

BUYING YOUR WATER?

PUMPING YOUR WATER?

DOES your community get the full benefit of the water it pays for? The water it pumps? A "Niagara" is wasted every year through leaky pipe joints.

The one best safeguard against leakage loss, contamination and costly repairs is Universal Cast Iron Pipe. Nothing to deteriorate, nothing to work loose in its machined iron-to-iron joints —no lead nor any other jointing material. No bell holes to dig.

Thousands of miles laid every year for dependable water supply and fire protection lines. Wrenches the only tools.

You, too, can install *this* cast iron pipe quicker and easier and solve that leakage problem.

The hub and spigot ends of Universal Pipe, machined at slightly different tapers, are drawn into direct contact forming flexible iron-to-iron joints that provide for expansion and contraction, vibration and uneven ground settlement.

Let our nearest office show you.

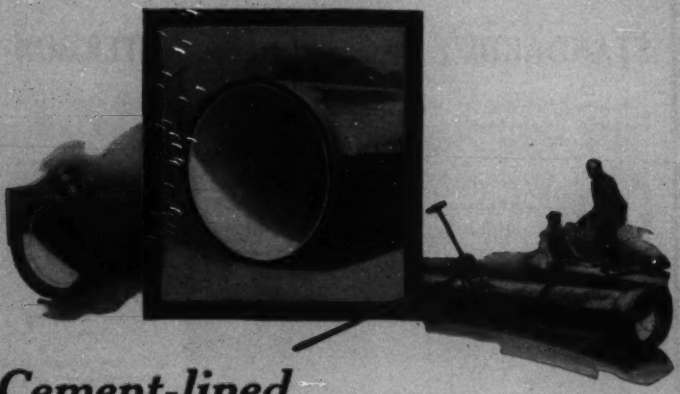
UNIVERSAL CAST IRON PIPE

No bell holes. No joints to calk.

THE CENTRAL FOUNDRY COMPANY

Subsidiary of The Universal Pipe and Radiator Company

Chicago Birmingham Dallas San Francisco



Cement-lined deLavaud Cast Iron Pipe

THE cement lining, when applied by the centrifugal method, is extremely dense and has a porcelain-like surface.

The lining adheres to the iron so tenaciously that the pipe can be cut or tapped without breaking the coating adjacent to the cut.

Moreover deLavaud centrifugal pipe, with its larger internal diameter, cement-lined by this method, has initially as great carrying capacity as ordinary pipe, nor is the flow reduced with age.

If you have any problem that involves the necessity of an absolutely non-corrosive pipe under all conditions, write to us for special literature covering the specifications, manufacture and uses of deLavaud centrifugal cement-lined cast iron pipe.

Write for details of the service we maintain for the assistance of Construction Engineers

United States Cast Iron Pipe and Foundry Company

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STANDARDIZE ON THE CLARK METER BOX

Houses all meters whether placed in boulevard, sidewalk or street in the same uniform and systematic manner and large meters as well as small ones.

A type and size to meet every climatic condition.

Why experiment when The Clark Meter Box has proven successful in thousands of Water Departments for over twenty years?

Perfect Locking Device

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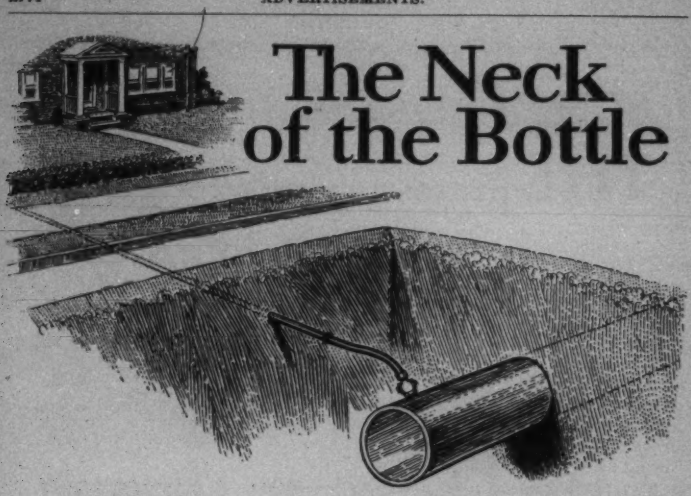

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